GEOPHYSICAL SURVEYS FOR ASSISTING IN DETERMINING THE GROUND WATER RESOURCES AT THE KAUPULEHU, PUAA AND KEAUHOU PROJECT AREAS ISLAND OF HAWAII

Prepared for:

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(CRC Project #9038-000)

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1.0 INTRODUCTION

This report contains the results of geophysical surveys conducted to assist in determining the ground water resources at three project areas (Kaupulehu, Puaa and Keauhou) on Bishop Estate properties in North Kona, Island of Hawaii. The surveys were performed by Coleman Energy & Environmental Systems - Blackhawk Geosciences Division (CEES-BGD) for Kamehameha Schools/Bernice Pauahi Bishop Estate and Kamahameha Investment Corporation (KIC) during June and July 1993. The locations of the three project areas are given in Figure 1-1.

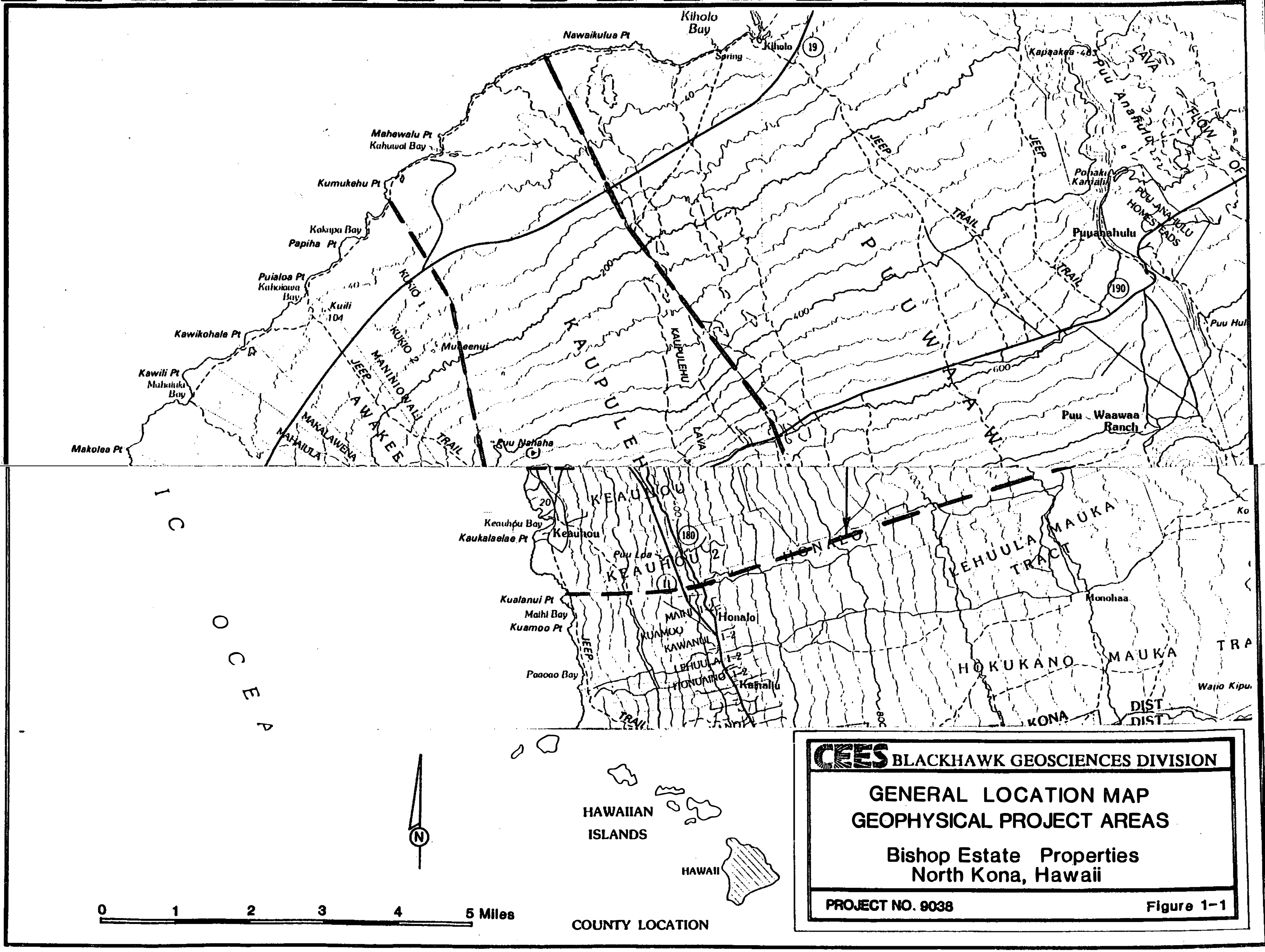
Ground water resources occur on the Hawaiian Islands basically in two modes:

- in a basal mode where a lens of fresh water flows on saline water, and
- in a high-level mode where the ground water occurrence is controlled by damming structures.

Figure 1-2 illustrates these two types of ground water occurrences. Previous time domain electromagnetic (TDEM) surveys on Hawaii have reliably mapped the boundary between fresh water in the basal mode and high-level water occurrences. This main boundary generally parallels the coast line in the north Kona area. From well production data near the Keauhou area, it is now evident that other secondary damming structures exist above and perpendicular to the main damming structure. A schematic geologic model that can help explain the two types of damming structures is shown in Figure 1-3. It outlines a major ring fracture developed from a caldera which is near parallel to the coast, and radial fractures which form near perpendicular to the major ring fracture. It is postulated that the fractures are zones of weakness where intrusive dikes preferentially form and these dikes can be impermeable. The radial fractures could divide the high-level water behind the ring fractures in different compartments. The water production from a single compartment will be determined by several factors including porosity, permeability, size of, and recharge to a compartment.

Based on the hydrologic information detailed above, the objectives for each of the three project areas are given in the following.

The main objective of the geophysical surveys at the Kaupulehu Project-Area 1 was to determine if high-level ground water occurs at locations above Highway #190. A ground water damming structure has been mapped by previous TDEM surveys near the Puaa Project-Area 2 at locations both north and south of the property, and the objective of the geophysical at Puaa survey was to determine if high-level ground water occurs above Highway #180 on the property. A main ground water damming structure (parallel to the coast line) is inferred to occur in the Keauhou Project-Area 3 and recent drilling results indicate that secondary damming structures may exist within the region above the main damming structure. The primary objective at the Keauhou Project Site was to test several different geophysical methods to attempt to map the position of the secondary damming structure(s). There are significant cultural features (power lines, pipelines, houses, etc.) in the Keauhou area. These features are known to significantly affect many geophysical methods, in particular, electrical and electromagnetic methods such as TDEM and also magnetic methods. Another objective of the survey in the Keauhou area was to test geophysical methods for their applicability in built-up (cultural) areas.



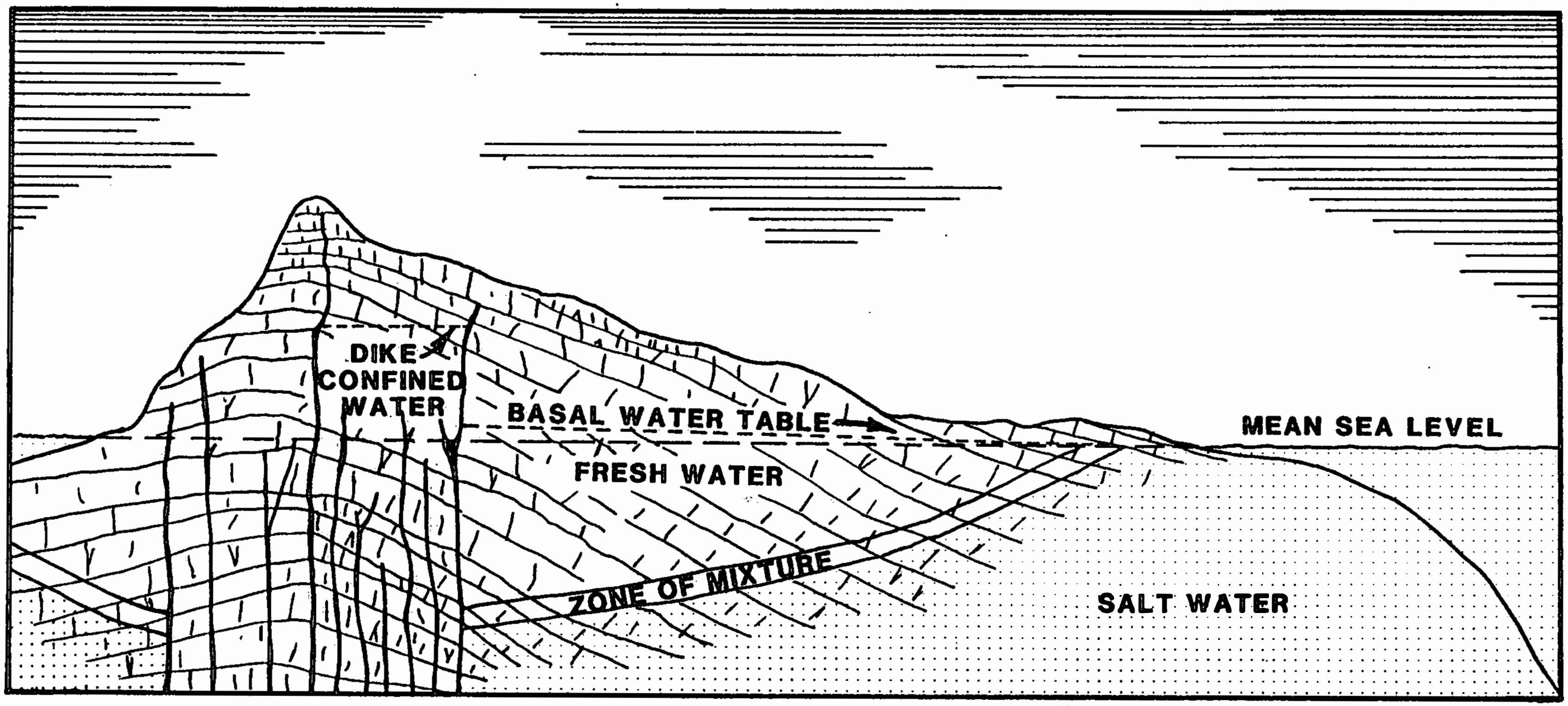
CEES BLACKHAWK GEOSCIENCES DIVISION

GENERAL LOCATION MAP
GEOPHYSICAL PROJECT AREAS

Bishop Estate Properties
North Kona, Hawaii

PROJECT NO. 9038

Figure 1-1



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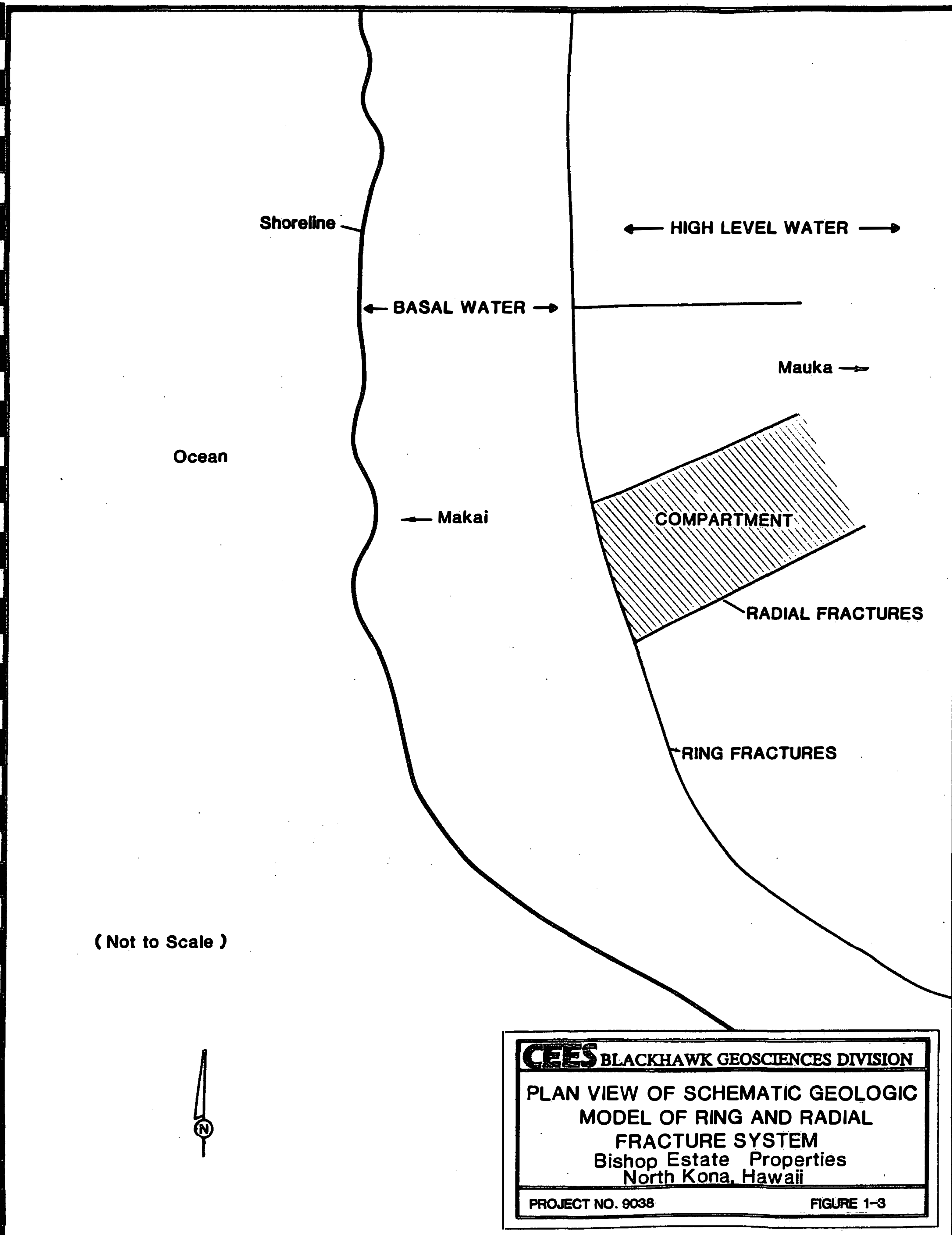
SCHEMATIC HYDROGEOLOGIC CROSS SECTION
Bishop Estate Properties
North Kona, Hawaii

PROJECT NO. 9038 FIGURE 1-2



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PLAN VIEW OF SCHEMATIC GEOLOGIC MODEL OF RING AND RADIAL FRACTURE SYSTEM
Bishop Estate Properties
North Kona, Hawaii

PROJECT NO. 9038

FIGURE 1-3

2.0 DESCRIPTION OF GEOPHYSICAL METHODS

2.1 GENERAL

The geophysical methods employed, and the primary objectives at each survey area, are summarized in Table 2-1.

Table 2-1
Geophysical Methods and Exploration Objectives

Survey Area	Geophysical Method(s) Used	Objective
Kaupulehu	TDEM soundings	Define presence and position of expected ground water damming structures.
Puaa	TDEM soundings	Define presence and position of expected ground water damming structures.
Keauhou	TDEM soundings, TDEM profiling, Gravity, Magnetics, Self Potential	Attempt to map secondary ground water damming structure.

TDEM soundings were recommended at the Kaupulehu and Puaa areas because previous surveys have shown that the boundary between basal and high-level ground water can be detected with TDEM. The mapping of the secondary ground water damming structure (i.e., radial structures) is an unproven application of surface geophysics and tests at the Keauhou area were made with several methods to prove their application. In addition, numerous cultural features (houses, fences, power lines, etc.) exist in the Keauhou area. These features will influence some of the geophysical methods proposed. Because of this problem, several different geophysical methods which have different sensitivity to cultural features were recommended for the tests at Keauhou. In the following sections, brief descriptions of the various geophysical methods are given.

2.2 TDEM SOUNDINGS

With TDEM soundings the resistivity layering (geoelectric section) of the subsurface is derived. A brief technical note describing the principles of TDEM is given in Appendix B. The translation of resistivity layering into hydrologic information is generally accomplished by two methods:

1) One method is to use available knowledge about the relation between resistivity values and local hydrology. From more than twenty previous TDEM surveys on the Hawaiian Islands, it has been observed that dry and fresh water saturated volcanics exhibit high resistivities, typically greater than 500 ohm-m. Conversely, volcanic rocks saturated with salt water

exhibit resistivities typically less than 5 ohm-m. Weathered volcanics or ash flows and intrusives often display intermediate resistivities (10 to 100 ohm-m).

Using this knowledge, characteristic ranges of resistivities expected for local hydrogeologic units for the Kaupulehu, Puaa and Keauhou Project areas are shown in Figure 2-1. It should be noted that some overlap in resistivities occur, but other factors are also used to infer the geologic/hydrologic unit in question. For example, a low resistivity unit (e.g., less than 10 ohm-m) occurring at an elevation above sea level is assumed to be caused by either intrusives or weathered rock formations rather than salt water saturated units.

2) Another method is to calibrate the geophysical interpretation at a well. At the Kaupulehu project, two wells were available for comparison with TDEM interpretation from a previous survey, located approximately 8,000 ft downslope from the present survey. Well information was not available for comparison in the immediate vicinity of the Puaa project area. Information from two wells was available for comparison in the Keauhau area.

2.3 TDEM PROFILING

TDEM profiling measurements were made at the Keauhou area to attempt to define the location of the expected secondary ground water damming structure. With TDEM profiling, a fixed transmitter loop is used and measurements are made at a number of stations on a profile through the loop. The schematic survey layout is illustrated in Figure 2-2. This mode of TDEM surveying has been used frequently in mining exploration programs to detect conductive ore bodies, and has proven effective in the past for detecting lateral changes in the geoelectric section, and in particular, vertical structures. It was postulated that the structure which creates the large difference in static water level at Keauhou may create significant lateral changes in resistivity. The advantages of TDEM profiling are large effective exploration depth, and ability to model two-dimensional (e.g., vertical dike-like) targets. A technical note (Massive Sulfide Target Detection) is given in Appendix B which describes the fundamentals of the TDEM profiling method.

TDEM soundings and profiling are moderately sensitive to cultural features.

2.4 GRAVITY AND MAGNETICS

Gravity and magnetic surveys were tested at the Keauhou area. Gravity surveys were recommended to try to exploit the density differences expected between the intrusive dikes and the volcanic host rock. Based on prior gravity surveys in the Kilauea area (Hill and Zucca, 1987), density contrasts were observed for intrusives, and large-scale intrusives were mapped. However, detectability of smaller scale intrusives was the objective at Keauhou and thus, limited detail gravity surveys were run at Keauhou. Gravity surveys are generally not affected by culture.

Ground magnetic surveys have apparently not been very successful in the past to map small-scale deep intrusive dikes in the volcanic host rock in Hawaii. Some success in mapping large-scale intrusive dikes with airborne magnetic data is reported by Flanigan and Long (1987) in the Kilauea and Mauna Lea rift systems, however, application to smaller scale features has not been reported. Magnetic surveys were recommended at the Keauhou area due to its low cost. Magnetic surveys are highly sensitive to cultural features.

2.5 SELF-POTENTIAL (SP)

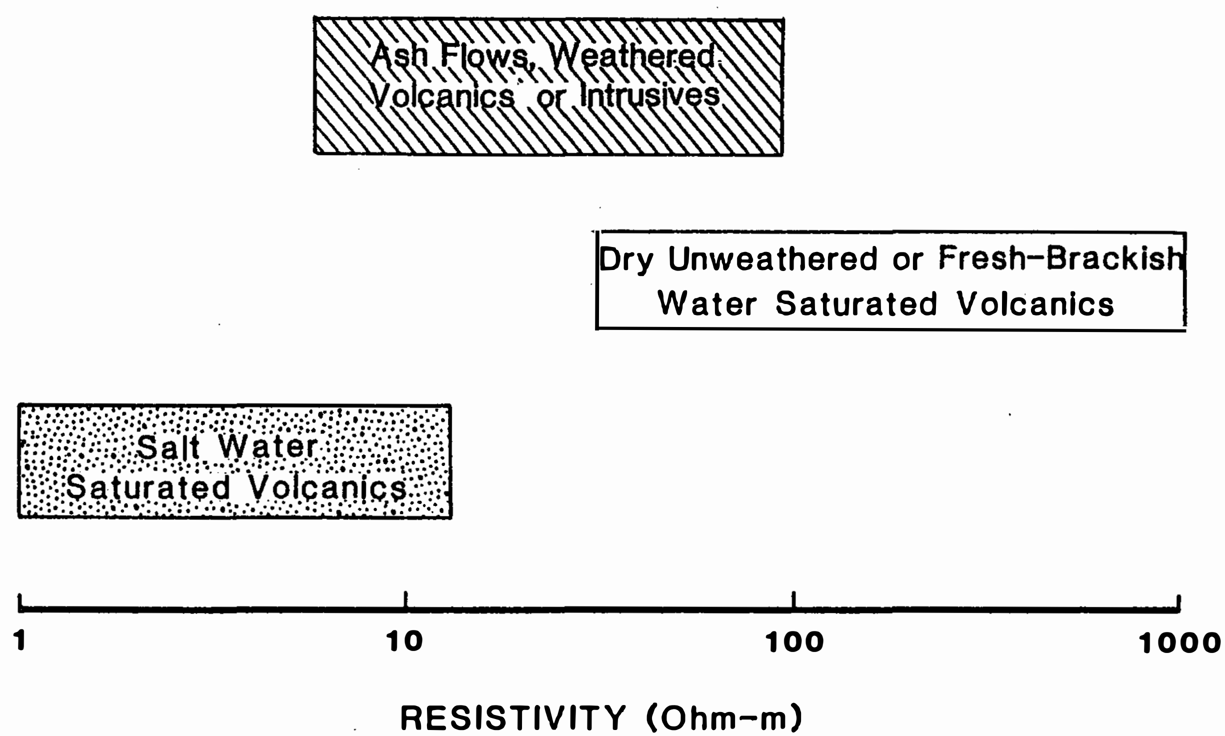
Self-potential (also known as Spontaneous Potential) surveys were conducted at the Keauhou area. Ground water flow in certain soil and rock types creates a spontaneous electrical current flow that can be measured as a potential at the surface. Because the static water level across the secondary structure (between the wells at Keauhou) differs, there might be some ground water flow across it, causing a measurable potential. Previous SP surveys (Jackson and Kauahikaua, 1987) near the Kilauea Volcano, indicate that SP data may correlate with topography and vadose zone thickness, and that an estimate of the water table elevation might be possible. Because SP surveys are relatively fast and inexpensive, they were recommended at Keauhou. SP surveys are relatively sensitive to cultural features.

<u>References</u>

Flanigan, V.J. and C.L. Long, 1987. Aeromagnetic and near-surface electrical expression of the Kilauea and Mauna Loa volcanic rift systems. Volcanism in Hawaii, Vol. 2, U.S.G.S. Professional Paper 1350, p. 935-946.

Hill, D.P. and J.J. Zucca, 1987. Geophysical constraints on the structure of Kilauea and Mauna Loa volcanics and some implications for seismomagnetic processes. Volcanism in Hawaii, Vol. 2, U.S.G.S. Professional Paper 1350, p. 903-917.

Jackson, D.B. and J. Kauahikaua, 1987. Regional self-potential anomalies at Kilauau Volcano. Volcanism in Hawaii, Vol 2, U.S.G.S. Professional Paper 1350, p. 947-959.



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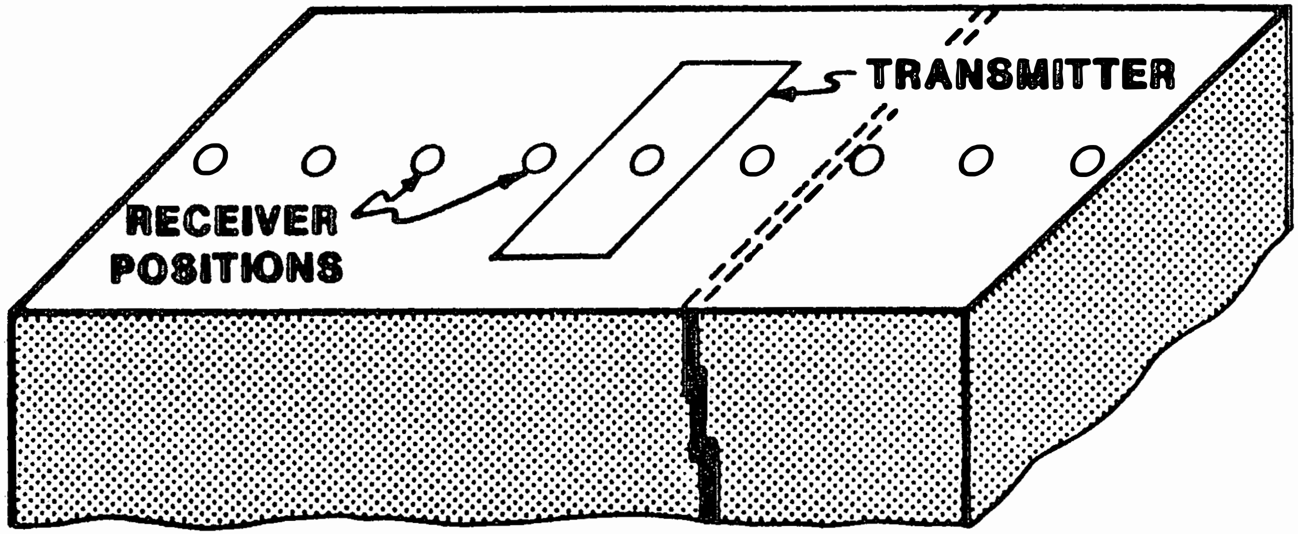
CHARACTERISTIC
RESISTIVITY RANGES

BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO: 9038

Figure 2-1

Fixed transmitter-
moving receiver.



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TRANSMITTER-RECEIVER ARRAY
PROPOSED FOR TEST SURVEY

Bishop Estates Properties
North Kona, Hawaii

FIGURE 2-2

3.0 DATA ACQUISITION AND LOGISTICS

The geophysical surveys for the three project areas were performed by a four and sometimes six man crew, consisting of two CEES-BGD geophysicists and two to four field helpers provided by Bishop Estate. A daily log of field activities is given in Table 3-1.

3.1 TDEM SURVEYS

During the surveys over the three areas, time domain electromagnetic (TDEM) measurements were mainly acquired using a central-loop sounding configuration. With this configuration, measurements are recorded with the receiver coil at the center of square transmitter loops laid on the ground surface. The transmitter loops are constructed with 12-gauge insulated copper wire. The dimensions of the loops vary depending upon the exploration depth required at each site (larger loop dimensions for deeper exploration depth). Transmitter loop sizes varied from 1,500 ft by 1,500 ft on the Kaupulehu Project-Area 1 to 500 ft by 500 ft on the Keauhou Project-Area 3. Sounding location and elevation control was based on compass and hip-chain measurements from known landmarks (i.e., roads, rock walls), and periodic altimeter measurements in the field.

The geophysical equipment used for the TDEM surveys was the Geonics EM37 TDEM system, using a transmitter current between 12 and 18 amperes at base frequencies of 3 Hz and 30 Hz. At the center of each transmitter loop the time derivative of the vertical magnetic field was recorded with receiver coils with effective areas of 100 m^2 and 1,000 m^2, when appropriate. The data from each sounding was stored in the field on an Omnidata Polycorder and subsequently transferred to a PC-386 for nightly processing. Two offset measurements symmetric about the loop center were also made at each sounding site to test for effects of inductive noise due to coupling with metallic structures, such as buried pipelines and power lines.

3.2 MAGNETIC SURVEYS

Magnetic data were acquired on traverse lines 1 and 2 at the Keauhou Project-Area 3 at 50 ft station intervals. Total field magnetics and magnetic gradient data were measured at each station with an EDA Instruments, Inc. PPM-500 Omnimag vertical gradiometer. The data from each station was stored in solid state memory in the magnetometer and downloaded to a PC-386 after each field day. A total of 10,300 linear ft of magnetic data were acquired over the two survey lines. Field notes were kept to document the locations of cultural features, such as fences and power lines, which affect magnetic measurements.

3.3 SELF-POTENTIAL (SP) SURVEYS

Self-Potential (SP) data were taken over a 8,300 ft linear distance on Line 1 at the Keauhou Project Area-3 using 100 ft potential spreads. For the SP measurements, the receiver circuit consists of a high-impedance volt-ohmmeter-receiver, two porous-pot potential electrodes in contact with the ground, and the potential spread wire. The porous-pots are firmly implanted on the moist ground surface (in this case at 100 ft separations) and measurements are taken with a volt-ohmmeter. A Fluke 77 volt-ohmmeter was used to measure the voltage and resistance across the two porous-pots. These two measurements are taken at each station and then the trailing porous-pot is moved up to the next station and the acquisition procedure is repeated.

3.4 GRAVITY SURVEYS

Gravity data were taken at the Keauhou area at 95 stations on roughly north-south and east-west lines. Where practical, measurements were taken at a nominal 200 ft station spacing. The instrument used for the survey was a modified LaCoste & Romberg Model G (Edcon-Super G meter). Drift in measurements was compensated for by frequent (maximum 2 hour) repeat measurements at a base station. Lateral position and elevation control for the measurement stations was accomplished by KIC personnel.

Table 3-1
Daily log of field activities

Date (1993)	Activity
June 21	Mobilize CEES-BGD personnel and equipment from Golden, CO to Kailua-Kona, Hawaii.
June 22	Unpack equipment and organize into vehicles for surveys. Meet with Bishop Estate personnel and their consulting hydrogeologist to discuss the geophysical surveys planned for Areas 1, 2 and 3.
June 23	Begin TDEM survey measurements on Kaupulehu Project (Area 1). Acquire data on Loop 1 and layout Tx Loop 2.
June 24	Take data on Loop 2 (Area 1). Move to Puaa Project (Area 2) and read Loop 1.
June 25	Meet with Bishop Estate personnel to discuss property status and drillhole locations at Keauhou (Area 3). Begin surveying on Line 1 between drillholes 2 and 3. Layout large (1,000 ft by 1,500 ft) Tx Loop A around drillhole 2.
June 26	Acquire TDEM profile data (Keauhou Project) with Tx Loop A on Line 1 from Station 0N to 2500N (25 stations) with 100 ft station increments.
June 27	Take Self-Potential (SP) data on Line 1 from Stations 1000S to 2500N and Line 2 from Stations 0W to 1800W. Pick-up Tx Loop A and layout Tx Loop B around drillhole 3.
June 28	Begin small (500 ft by 500 ft) Tx Loop TDEM measurements on Line 1. Read Station 250S.
June 29	Acquire TDEM profile data with Tx Loop B on Line 1 from Station 1900N to 800S (25 stations).
June 30	Acquire small Tx Loop TDEM soundings on Line 1. Read Soundings 250N, 750N and 1250N. Begin gravity measurements. Read stations G40 (Base), and G20 through G29.
July 1	Continue small Tx Loop TDEM soundings. Read Soundings 1750N, 2250N and 2750N. Gravity measurements at G29 through G59 and G19 through G15.
July 2	Continue small TX Loop Soundings. Read 3250N, 3750N and 4250N. Gravity measurements at G63 through G79.
July 3	Take SP data on Line 1 from Station 2300N to 5500N. Read magnetic data on Line 1 from Station 1500N to 3000S. Gravity measurements at G63 through G79.
July 4	Take magnetic data on Line 1 from Station 1500N to 5500N and Line 2 from Station 0W to 1800W. Gravity measurements at G80 through G95 (end of gravity survey).
July 5	Pack and ship gravity meter at United Air Freight.
July 6	Acquire TDEM Sounding 3 on Kaupulehu Project (Area 1).
July 12	Continue small Tx Loop soundings on Line 1. Read Soundings 4750N and 5250N.
July 13	Small Tx Loop soundings on Line 1. Read Soundings 5750N, 6250N, 6750N, 7250N, 7750N and 8250N.
July 14	Pack and demobilize equipment from Kailua-Kona, Hawaii.
July 15	Demobilize CEES-BGD personnel from Kailua-Kona, HI to Golden, CO.

4.0 DATA PROCESSING

4.1 TDEM DATA

The first step in processing TDEM data is to average the electromotive forces (emfs) recorded at opposite receiver polarities. Next, the recordings made at different amplifier gains and frequencies were combined to give one transient decay. The emf's in the various time gates of the decay curves are subsequently entered into a ridge regression inversion program to obtain a one-dimensional (1-D) geoelectric section that matches the observed decay curve.

The inversion program requires an initial model for the geoelectric section. This model is usually derived from approximate matching of apparent resistivity curves with model curves from a series of albums of model curves or from a knowledge of the geoelectric section obtained from drillhole logs. The inversion program is then allowed to adjust the model to improve the fit. This involves the adjustment of resistivities and thicknesses of the layers within the geoelectric model. The inversion program does not change the total number of layers within the model, but all other parameters float freely, or optionally can be held constant. To determine the influence of number of layers on the solution, separate inversions with a different number of layers are run.

An example of the output of the inversion program for Sounding HUAL1 is given in Figure 4-1. The measured data points (in terms of apparent resistivity) are superimposed on a solid line. The solid line represents the computed forward model for the geoelectric section shown on the right. This geoelectric section is the best match obtained by the inversion program. Tabulated inversion parameters consisting of measured data, computed data for best match solution, and inversion error are given in Figure 4-2. The geoelectric section in turn is translated into hydrogeologic information by establishing a relationship between resistivity and hydrogeologic units. Inversion plots and tables for all soundings are given in Appendix A.

4.2 MAGNETIC DATA

Simple processing of the magnetic data requires correction for diurnal time variations (drift). During the survey this was accomplished by repeating readings in the same magnetometer orientation at a designated base station at 1 to 2 hour intervals during the survey. The diurnal drift during data acquisition is then added or subtracted from each reading by linearly distributing the drift on the traverse line data over the 1 to 2 hour interval. After the drift correction is applied to the data, profile plots of total field magnetics and magnetic gradient versus stations are made.

4.3 SELF-POTENTIAL (SP) DATA

During acquisition of the SP data, the voltage and resistance between the two porous-pots is measured. Simple processing of the SP data requires addition of the first potential spread reading to the second spread reading to arrive at the cumulative voltage (millivolts) reading for the second spread. This addition is performed across the entire traverse line and the result is a profile plot of cumulative voltage versus stations.

4.4 GRAVITY DATA

Metered Gravity

The meter readings taken from the gravimeter are a function of the tension on the nulling spring of the gravimeter. Several steps are required to convert these readings into the earth's gravitational field (units of milligals).

The first step in this process is to multiply the readings by a meter factor. After reading has been corrected for the meter factor, it is then corrected using the free-air gradient for the height of the meter above the surveyed station elevation. Earth tides are then compensated for in the readings.

Tides refer to the upward gravitational attraction of the sun and moon at the earth's surface. The rigid earth solar plus lunar tide is calculated and then multiplied by 1.16 to correct for the earth's compliance and the product is then added to the meter readings to obtain tide corrected gravity.

Application of meter factors, tide corrections, and variable meter height above ground level converts the meter readings into metered gravity in milligals. Once the readings have been converted to milligals, the meter drift is removed by using the values recorded at the base station. Twenty-nine base station measurements were recorded over the duration of the survey. The base station location for this survey was station G-40.

Once the drift corrections have been made to the metered gravities, the differences between the field station and the base station are added to the absolute gravity at the base station to obtain the absolute gravity at the field station.

Theoretical and Residual Gravities

Residual gravity is the difference between the absolute gravity and the theoretical gravity:

$$G_{Residual} = G_{absolute} - G_{theoretical}$$

There are several different definitions for residual gravity depending on the factors included in the calculation of theoretical gravity. These factors include:

FACTOR	DESCRIPTION
REFERENCE ELLIPSOID	Gravity on a sea level, rotating ellipsoidal model of the Earth (a function of latitude).
FREE-AIR EFFECT	The decrease in gravity with elevation due to increasing distance from the center of the Earth.
BOUGUER-SLAB EFFECT	The attraction of the slab of material between the station elevation and sea level.
TERRAIN CORRECTION	The decrease in gravity due to the upward pull of adjacent topographic features which are higher than the station (hills) and the lack of a downward pull from open space which is lower than the station (valleys).

The Bouguer slab correction requires a knowledge of, or assumption of, the mean density of the material between the station elevation and sea level. For this study, a Bouguer slab density of 2.1 gm/cc was used.

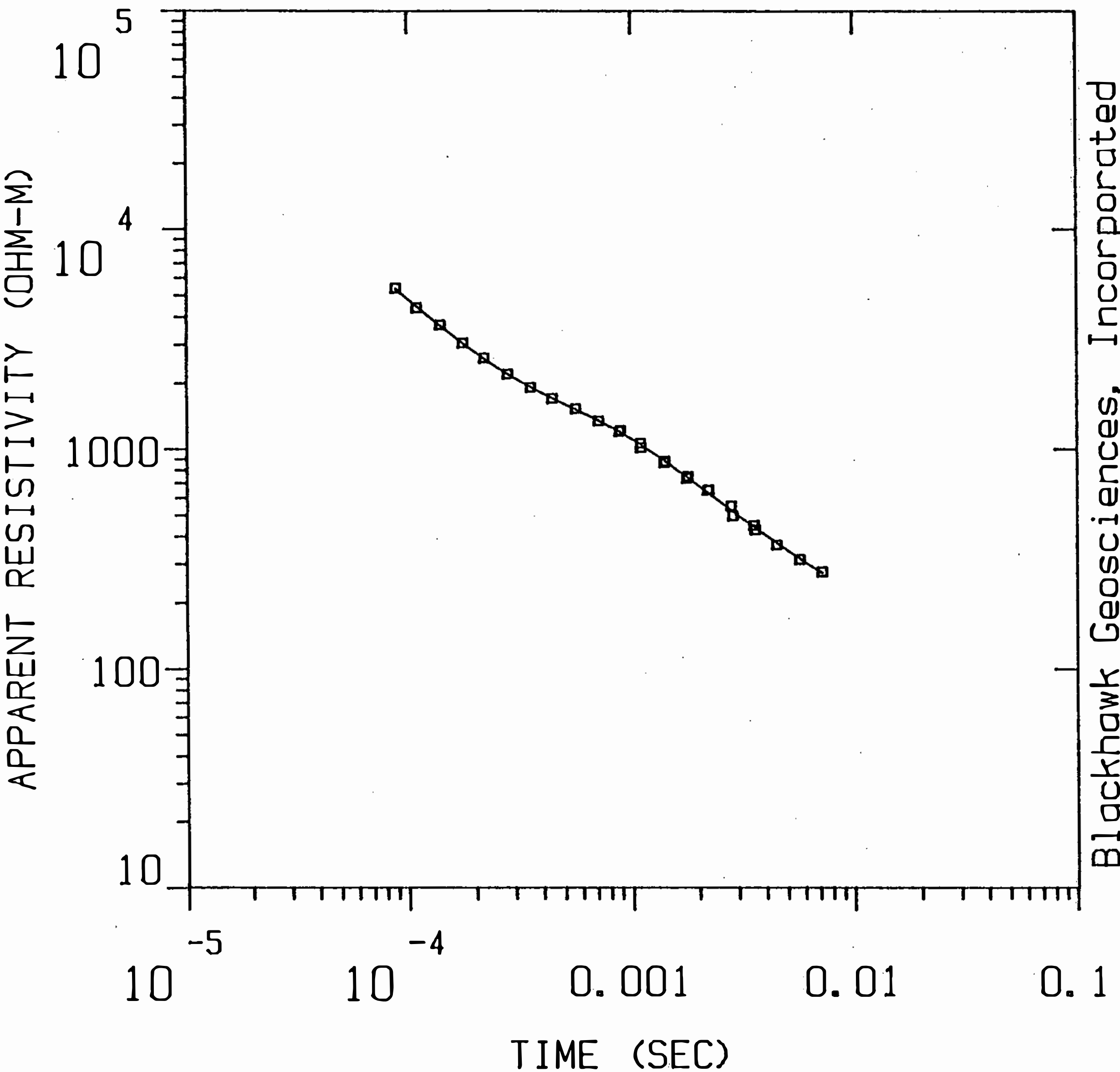
"Free-air gravity" indicates that the reference ellipsoid and free-air effect were included in calculating the theoretical gravity. "Simple Bouguer gravity" indicates that the reference ellipsoids, free-air effect, and Bouguer slab effect are included. "Bouguer gravity" indicates that all these factors, plus terrain corrections, are included. The corrections included are listed in Table 4-1.

Table 4-1
List of Corrections Included in Different Definitions of Residual Gravity

ABSOLUTE GRAVITY	**REFERENCE ELLIPSOID**	**FREE-AIR EFFECT**	**BOUGUER-SLAB EFFECT**	**TERRAIN CORRECTION**
FREE-AIR GRAVITY	YES	YES		
SIMPLE BOUGUER GRAVITY	YES	YES	YES	
BOUGUER GRAVITY	YES	YES	YES	YES

Variations in the Bouguer gravity over a site are due to lateral variations in subsurface density. It is these gravity variations which are interpreted by creating geologically-reasonable density models.

HUAL 1



MODEL:

2081. OHM-M 409. M

360. OHM-M 436. M

53.0 OHM-M

% ERROR: 3.05
CALIBRATION: 1
OFFSET: 228. M
RAMP: 220.0

CEES BLACKHAWK GEOSCIENCES DIVISION

EXAMPLE DATA SET
SOUNDING HUAL 1
KAUPULHU PROJECT - AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 4-1

HUAL1

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		707.1	2320.0		
2081.13	408.5	298.6	979.7	0.2	0.2
359.72	436.4	-137.8	-452.0	1.2	1.4
52.97					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.38E+03	5.33E+03	0.931	
2	1.10E-04	4.38E+03	4.47E+03	-1.909	
3	1.40E-04	3.68E+03	3.66E+03	0.400	
4	1.77E-04	3.04E+03	3.04E+03	0.127	
5	2.20E-04	2.61E+03	2.59E+03	0.805	
6	2.80E-04	2.20E+03	2.20E+03	-0.021	
7	3.55E-04	1.91E+03	1.91E+03	-0.148	
8	4.43E-04	1.70E+03	1.70E+03	-0.266	
9	5.64E-04	1.52E+03	1.51E+03	0.820	
10	7.13E-04	1.34E+03	1.34E+03	-0.138	
11	8.81E-04	1.20E+03	1.20E+03	0.135	
12	8.90E-04	1.21E+03	1.19E+03	1.639	
13	1.10E-03	1.06E+03	1.05E+03	0.923	
14	1.10E-03	1.01E+03	1.04E+03	-3.156	
15	1.40E-03	8.64E+02	8.86E+02	-2.485	
16	1.41E-03	8.80E+02	8.81E+02	-0.143	
17	1.77E-03	7.33E+02	7.46E+02	-1.745	
18	1.80E-03	7.50E+02	7.39E+02	1.549	
19	2.20E-03	6.50E+02	6.33E+02	2.647	
20	2.22E-03	6.52E+02	6.28E+02	3.827	
21	2.80E-03	5.50E+02	5.27E+02	4.369	
22	2.85E-03	4.96E+02	5.20E+02	-4.721	
23	3.55E-03	4.48E+02	4.42E+02	1.409	
24	3.60E-03	4.28E+02	4.37E+02	-2.038	
25	4.49E-03	3.65E+02	3.73E+02	-2.108	
26	5.70E-03	3.13E+02	3.16E+02	-0.938	
27	7.19E-03	2.76E+02	2.72E+02	1.434	

R: 228. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
CLHZ ARRAY, 27 DATA POINTS, RAMP: 220.0 MICROSEC, DATA: HUAL1
2306 100 111NZ OPR XTL L 6 10-100
Ch.21 = 0.22 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 20
RMS LOG ERROR: 1.30E-02, ANTILOG YIELDS 3.0461 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.99				
P 2	0.00	0.99			
P 3	0.00	0.00	1.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	P 3	T 1	T 2

CEES BLACKHAWK GEOSCIENCES DIVISION

EXAMPLE DATA SET
SOUNDING HUAL 1
KAUPULEHU PROJECT – AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 3038 FIGURE 4-2

5.0 RESULTS

5.1 KAUPULEHU PROJECT-AREA 1

During the geophysical surveys at the Kaupulehu project three TDEM sounding measurements were acquired above and below Highway #190. The location map of the project area is given in Figure 5-1. On this figure is shown the Area 1 boundary, locations of the soundings taken during the present survey, and the locations of soundings from two previous TDEM surveys which have been incorporated into this data set. The results of the TDEM interpretations are presented as four separate geoelectric cross sections. The path of the geoelectric sections is also shown on Figure 5-1.

<u>Geoelectric Cross Section A-A'</u>

Figure 5-2 shows the results of three TDEM soundings presented as a south to north trending geoelectric cross section (A-A'), in which layers that exhibit similar resistivity values have been linked together.

The upper layer of the section, below all three soundings, displays resistivities ranging from 1682 to 5712 ohm-m. This upper layer is interpreted to represent dry unweathered volcanics above sea level and where it occurs below sea level it is expected to be saturated with fresh-brackish basal mode water. The lower layer beneath Sounding B exhibits a resistivity of 6.8 ohm-m, which is interpreted to represent salt water saturated volcanics. The approximate thickness of the fresh-brackish water lens is 340 ft beneath Sounding B.

Soundings H1 and C are located in a structurally complex area. A salt water interface is not interpreted and intermediate resistivity values are exhibited above and below sea level. Beneath Soundings H1 and C resistivity values range from 53 to 54 ohm-m and these values are expected to be caused by influence from lateral discontinuities (i.e., faults, dikes). Because of rapid lateral variation in resistivity, the interpreted resistivity stratification may not represent true formation resistivities. Since the salt water interface was not interpreted beneath these two soundings, the elevation of the water table cannot be estimated.

Geoelectric Cross Section B-B'

The cross section results for B-B' is shown in Figure 5-3. The upper layer of the section exhibits high resistivity values ranging from 478 to 5712 ohm-m. These high resistivity values are interpreted to be dry unweathered volcanics above sea level and below sea level at Sounding B the volcanics are expected to be saturated with fresh-brackish basal mode water. Sounding H3 is expected to be located in the near vicinity of a ground water damming structure.

Beneath sounding H2 a layer with a resistivity of less than 5 ohm-m was not observed within the effective exploration depth of about 750 ft below msl, and thus neither salt water saturated volcanics or structures are inferred. Because Sounding H2 is located above the interpreted geologic/hydrologic structure, there is good potential for high-level water in this vicinity. From the cross section, the exact location of the upper (inland) hydrogeologic boundary is difficult to determine exactly with the existing data density. The existing TDEM information would place the boundary somewhere between the two soundings.

Geoelectric Cross Section C-C'

Figure 5-4 displays the results for cross section C-C' from Soundings H1 and H2. The interpretation of these soundings was given previously in descriptions of geoelectric sections A-A' and B-B' (Figs. 5-2 and 5-3, respectively). For review, Sounding H1 was interpreted to be located in the near vicinity of a ground water damming structure, and Sounding H2 was interpreted to lie in an area of potential high-level ground water.

Geoelectric Cross Section D-D'

The geoelectric cross section for D-D' is shown in Figure 5-5. The data for this cross section were acquired during two previous TDEM surveys which were located downslope from the present survey. Along this section, data from two wells were available for comparison to help calibrate the geophysical interpretation. The location of the two wells are between Soundings 1 and 2, with a separation of approximately 100 ft between the wells. The two wells show static water levels (head) of 6.9 ft and 12.6 ft. This large difference in head over such a short horizontal distance can be explained by possible errors in a head measurement or geologic structures (faults or dikes) in this vicinity which affect ground water flow. Soundings 2, 3 and 4 show intermediate resistivity layers (28 to 43 ohm-m) slightly below sea level and are interpreted to lie in an area of geologic structures. The lateral location of the structure on this section is uncertain, however it is expected to lie between Soundings 2 and A. ||??

Beneath soundings A and B, the salt water interface is interpreted and the approximate thickness of the fresh-brackish water lens is expected to be 434 ft beneath Sounding A and 343 ft beneath Sounding B.

5.1.1 Hydrogeologic Interpretations (Kaupulehu Project-Area 1)

The results of the TDEM soundings are further summarized on the interpretation summary map shown in Figure 5-6. The soundings are separated into three main groups and marked by a color code:

1) Two soundings (A and B-blue) beneath which a layer of low resistivity (6.8 ohm-m) was detected below sea level. A fresh-brackish water lens is expected to exist in the basal mode below these two soundings. The approximate thickness of the lens floating on salt water is expected to vary from approximately 430 ft at Sounding A to 340 ft at Sounding B.

2) A group of soundings (1, 2, 3, 4, C, H1 and H3) in which resistivities are influenced by lateral discontinuities and geologic/hydrologic ground water damming structures are inferred (green). Intermediate resistivity values occur both above and below sea level in this area. Ground water levels, water quality, and production are expected to be highly variable in these areas.

3) One sounding (H2) in which high resistivity values are interpreted to the effective exploration depth of about 750 ft below msl (yellow). In this area, the potential for high-level water exists.

The accuracy of determining the position of the interpreted ground water damming structures at the Kapulehu area is mainly determined by data density (station spacing). Better definition of the lateral limits of the boundaries could be made with additional TDEM soundings.

5.2 PUAA PROJECT-AREA 2

On Figure 5-7 the location for the one sounding acquired on the Puaa Project is shown. The geoelectric section for Sounding Puaa 1 is shown in Figure 5-8. The upper layer of the section exhibits resistivity values ranging from 107 to 5605 ohm-m, which are interpreted to represent dry unweathered volcanics above sea level. The lower layer at this sounding exhibits an intermediate resistivity of

21 ohm-m which occurs near sea level and is interpreted to be caused by ground water damming structures (i.e., faults or dikes).

To the north and south of Sounding Puaa 1, a ground water damming structure has been mapped by previous TDEM surveys. Because Sounding Puaa 1 is interpreted to be located within the geologic/hydrologic structure, there is good potential for high-level ground water upslope from this location. Additional TDEM soundings upslope from Puaa 1 would help to confirm the position of the expected boundary and help confirm the existence of high-level ground water.

5.3 KEAUHOU PROJECT-AREA 3

5.3.1 General

The location of the geophysical measurement positions at the Keauhou area are shown on Figure 5-9. As mentioned in Section 1.0, the primary goal of the geophysical surveys at Keauhou were to determine if geophysical methods could detect a secondary ground water damming structure which is postulated to exist between wells 2 and 3. It was reported that both wells 2 and 3 encountered high-level water with static water levels (heads) of 286 and 388 ft asl, respectively. The distance between the wells is only approximately 1,500 ft, and therefore a ground water damming structure was inferred. Additional data were also collected to the north (to well 4 and beyond) to assess the potential for secondary ground water damming structures in this area. The geophysical methods tested at Keauhou were TDEM soundings, TDEM profiling, gravity, magnetics and self-potential.

5.3.2 TDEM Soundings

The geoelectric section from TDEM soundings taken along line 1 (ref. Fig. 5-9) is shown on Figure 5-10. The data were taken from contiguous 500 ft by 500 ft transmitter loops. Soundings taken at stations 250S, 1750N, 2250N and 2750N were affected by power lines, fences, etc., and could not be used in the geoelectric section. On the geoelectric section there are two areas where low resistivity zones are detected. These are: (i) between stations 250N and 1250N, and (ii) between stations 5250N and 6750N. The low resistivity zones are expected to be significant because past surveys indicate that low resistivity zones may be caused by geologic structures, ash flows or weathered volcanics, all of which have the potential to form ground water barriers. The low resistivity zone between 250N and 1250N displays an apparent dip to the south at about 20^{o} to 40^{o}. The zone is interpreted to extend from about 257 ft below sea level at station 250N to about 440 ft above sea level at station 1250N. The positions of wells 2, 3 and 4 are shown on the geoelectric section along with the static water levels at wells 2 and 3. Information from well 4 was not made available at the time of this report. From the comparison of the TDEM data and wells 2 and 3, it is expected that the conductive feature detected in the TDEM soundings between 250N and 2250N is related to the geologic feature which creates the variation in head between the two wells. Between wells 2 and 3 (soundings 250N, 750N and 1250N) a thin, high resistivity layer lies adjacent (above) the conductive layer. This layer may represent dense and more impermeable lavas which could also contribute to the discontinuity in ground water levels between the two wells.

The low resistivity zones detected between stations 5250N and 6750 N occur below sea level and thus, based on TDEM sounding data alone, they would not be expected to have significant influence upon the high level ground water in the area. A thin (54 ft) conductive layer is detected at station 8250N at a depth of approximately 950 ft. This layer may represent an altered lava flow or ash flow and is expected to have a minor impact on ground water levels along this section. More data would have to taken north of this location to determine the extent and significance of this layer.

The geologic/hydrologic interpretation of the apparent dipping conductive-resistive package between stations 250N and 1250N is speculative. This package could be due to a combination dike-sill intrusive or an extrusive flow sequence. However, for a dike complex, one would expect a more vertical orientation than that shown, and for a sill or flow, one would expect a more horizontal orientation than that shown.

It is known that TDEM soundings may become distorted in the vicinity of vertical structures. The interpretation of the data in the vicinity of such structures will be in error because the inversion routines use horizontal 1-D models. At present it is not economical or practical to interpret TDEM data with 2-D or 3-D models. However, recognition of vertical geologic contacts (2-D and 3-D structures) is possible from horizontal field data collected in the center of the loop (M.J. Wilt, 1991). In this survey the horizontal fields were collected at the center of each loop and the results are plotted on Figure 5-11. On this figure the vertical (z) and two horizontal components (x and y) of the TDEM field are shown. In horizontally layered ground with little lateral variation, the behavior of these fields would be relatively flat or smoothly varying. Along this line an anomalous response in all three components is detected at station 250S and from 1250N to about 2750N. These anomalous responses are caused by power lines, fences and electric fences noted on the figures.

No other significant anomalies are observed in the data which would suggest strong 2-D or 3-D structures.

The cultural interference from power lines and fences near station 250S and between 1750N and 2250N is also evident in the sounding data from offset measurements. At each station, measurements were taken in the loop center and at two offset positions (50 ft either side of the center). In areas where interference from cultural sources is present, the three measurements will differ. Figure 5-12 shows the center-loop and offset measurements for soundings 750N through 3750N. Soundings 1750N, 2250N and 2750N all show distortions due to cultural interference. For this reason, the data were not used in the interpretation.

5.3.3 TDEM Profiling

TDEM profiling measurements were taken along line 1 from two large (1000 ft by 1500 ft) fixed loops as shown on Figure 5-9. Two transmitter loops were used to create different geometric coupling between the transmitter and expected target. If targets are detected, this change in coupling can simplify interpretation. In addition, it is sometimes possible (however unlikely) that one transmitter loop may be minimum coupled to the target and in this case the target cannot be detected. The data taken from Loop A is shown on Figure 5-13 and the data taken from Loop B is shown on Figure 5-14. The profile data from Loop A is dominated by the cultural response from the power line and fence located near station 2000N. The effect from the power line and fence located near station 200S (off the end of the line) is also partially evident in the data. Other fences and power lines which intersect the profile do not appear to affect the data. There is no indication in the data of subsurface vertical structures.

The profile data from Loop B is again dominated by cultural responses from power lines and fences located at 200S and off-line at 2000N. No subsurface structures are evident in the data.

These profile data show large distortion in the electromagnetic field near the power lines and fences at 200S and 2000N, while other fences and power lines have little effect on the data.

5.3.4 Gravity

Gravity data were taken at locations shown on Figure 5-9. The primary objective of the gravity survey was to determine if the expected structure between wells 2 and 3 could be detected by its change in density. Other data were taken on a roughly east-west line to determine if the main ground water damming structure could be mapped based on density contrasts. Because gravity measurements are unaffected by culture, this method, if successful, could hold promise in cultural or populated areas. Measurement stations were selected on the basis of ease of access (since regular base station repeats are necessary), and anticipated ease of elevation surveying. Although unaffected by culture, there are many sources of noise in gravity data, including instrument reading errors, errors caused by elevation survey errors, errors caused by incorrect terrain or Bouguer slab corrections, etc. Gravity data and other potential field data (i.e., magnetics) are also prone to large equivalence in interpretation. This means that many different models can fit the data with nearly equivalent errors. By combining different potential field data or potential field data with other information (borehole, TDEM, etc.) some equivalence can be reduced. In the gravity modeling in the subsequent sections, a background gravity value of 2.1 g/ccm was used.

5.3.4.1 Line 1

Gravity data taken along a roughly north-south transect (Fig. 5-9) were grouped together to form gravity profile 1. This profile corresponds to the same measurement profile as the TDEM data for the south part of the profile, but deviate from the TDEM data on the north end of the profile.

A first pass interpretation of the gravity data was performed by modeling the data to an infinitely long horizontal polygon oriented perpendicular to the gravity profile. The results of this modeling are shown on Figure 5-15. This figure shows the ground surface and the depth to a layer which has a + 0.3 g/ccm contrast with the surface material. This modeling shows the approximate position of potentially significant gravity bodies, i.e., near 2600S, between 0 and 1000N and near 5000N.

The gravity data were subsequently modeled using separate finite dimension bodies as shown in Figures 5-16 and 5-17. In Figure 5-16 the gravity data (small squares) are shown in the upper part of the figure, along with the forward model calculation (solid line) for the model shown in the bottom portion of the figure. In this figure the data are adequately modeled using a host rock density of 2.1 g/ccm and four infinitely long polygons. The large gravity anomaly centered near 400N can be modeled with two bodies (densities of 2.54 and 2.4 g/ccm) which lie between station 0 and 1000N. These bodies could represent near vertical dike-like intrusive bodies. Another significant gravity anomaly is detected at about 4800N but is not totally defined with the existing data. This anomaly is matched with a body with a density of 2.59 g/ccm.

In Figure 5-17 the line 1 data are matched with three bodies. The error in fit between model and data is essentially the same as for Figure 5-16, however, a single body was used to match the large anomaly centered near 400N. This single body is more horizontal and could represent a sill or confined dense lava flow.

In Figure 5-18 the data were matched to a sequence of vertical infinitely long bodies. Again, the field data can be adequately matched to these bodies. This model could represent a sequence of vertical dikes which cut the profile at a 90° angle. The bodies which show significantly higher densities than background are indicated. These bodies may represent denser intrusive bodies.

The results of the gravity modeling show that several different gravity models will adequately fit the data. In all cases, however, a significant, denser, body or bodies must exist near stations 2500S, between 0 and 1000N and near 5000N. Also, in all cases the lateral position width and depth to the top of the bodies (or combined bodies) remains nearly the same. In the case of the large anomaly centered near station 400N, the width of the body (or combined bodies) is generally about 1,000 ft and is positioned generally between station 0 and 1000N. The depth to the top of the body (or combined bodies) is generally about 300 to 500 ft.

The gravity bodies which are believed to have a major impact on ground water resources in the Keauhou area are located between 0 and 1000N and near 5000N.

5.3.4.2 Line 2

Gravity data taken along a roughly east-west transect (Fig. 5-9) were grouped together to form gravity profile 2. This profile and model results using a sequence of infinitely long confined bodies are shown on Figure 5-19. The gravity data taken along this profile show significant scatter (noise) and are particularly noisy from about 5500W to 2800W. These data were checked for consistency (from repeat readings), and terrain corrections and Bouguer slab corrections were double checked. Elevation control was checked by a separate loop in this area. At present, there is no explanation for the noise in the data along this section of the profile. Because there is significant elevation change along this transect (approximately 1,100 ft) there may have been complications caused by elevation control or terrain corrections.

The significant gravity bodies on this line are noted on the figure and occur near 2300W, 0 and 1200E. The dense body near 4000W (2.68 g/ccm) is located in the area where the noise in the data is high and is not considered reliable. The denser body near 2500E (2.61 g/ccm) is also located in an area where noise in the data is high and in addition is not fully defined with the existing data coverage.

5.3.5 Magnetics

Magnetic data were taken along Line 1 (same as TDEM Line 1, Fig. 5-9) and also along Line 2. Both data sets were extremely biased by the cultural features in the area. The data from Line 2 was unusable. The raw data (both total field and gradient) from Line 1 are shown in Figure 5-20. Significant interference from each surface cultural feature (noted from field records) and other features which were not apparent on the surface (suspected to be buried trash, pipelines, power lines, etc.) are evident in the data as high amplitude, short spatial wavelength spikes. In an effort to gain useful information from this data, spatial filters were applied. In Figure 5-21 the magnetics data along Line 1 were filtered (using a 500 ft low pass spatial filter) and modeled with infinitely long vertical bodies. For the magnetics data (similar to gravity data) equivalence in solutions is very high. Because of the uncertainty associated with the noisy data the simplest starting model was used. The starting parameters for each body are:

1) Koenigsberger Ratio = 15 to 20 (ratio of natural remnant magnetization and induced magnetization).

2) Susceptibility (K) = .010 cgs units for bodies and .001 cgs units for background.

3) Inclination of body and background remnant magnetization = 35^{o} N (parallel to Earth's magnetic field).

4) Declination of body and background remnant magnetization = 11^{o} W (parallel to Earth's magnetic field).

5) Bodies are perpendicular to profile lines and have infinite extent.

These values are consistent with measurements and assumptions made by U.S.G.S. personnel (Flanigan and Long, 1987 and Hildenbrand, Rosenbaum and Kawahikaua, 1993) in previous studies on the Island of Hawaii. These values are considered the simple case because it has been shown that a significant change in anomaly shape, and therefore in interpretation, can arise if the direction of the remnant magnetization (inclination and declination) of intrusive bodies is different than that assumed in the modeling.

Figure 5-21 shows that the data can be adequately matched using a sequence of bodies which have a fairly small range of magnetic susceptibilities (0.01 to 0.012). The match to the data is essentially accomplished by moving the body (or bodies) closer to the surface (and thus closer to the measurement device) in the vicinity of anomalies. All anomalies on this line have relatively short wavelength and are caused by shallow targets. Average depth to top of bodies is less than 200 ft. No significant deep (greater than 1,000 ft) magnetic bodies are evident in the data.

5.3.6 Self Potential (S.P.)

S.P. data were collected on Line 1 (ref. Fig. 5-9) at the Keauhou area, and are presented on Figure 5-22. Some interference from cultural features is evident in the data, however, in general, the data appear to be adequate. The interpretation of S.P. data is somewhat ambiguous due to the complicated nature of the sources of Self Potentials. Regional S.P. studies at the Kilauea Volcano (Jackson and Kauahikaua, 1987) describe the possible sources of Self Potentials (Thermoelectric Coupling and Electrokinetic Coupling) and also describe S.P. correlations with topography and vadose zone thickness. Typically, quantitative interpretations of S.P. data cannot be made. The qualitative interpretative scenarios which are important at Keauhou are:

1) Electrokinetic Coupling - electric potentials generally become more positive in the direction of ground water flow.

2) Electrokinetic Coupling - there is some evidence that electric potentials increase as the depth to the vadose zone (and in turn the water table) decrease. Or in other words, as the vadose zone thickness increases.

Using these qualitative interpretative methods, the S.P. data on Line 1 may suggest:

1) Directions of ground water flow are towards the positive peaks in S.P. data near Station 0 (well #3) and towards Stations 3000N to 6000N, and/or

2) Depth to water table may decrease (slightly) towards Station 0 and from Station 1500N (well 2) towards 4000N (well 4).

The measured static water level in well #3 is 388 ft asl and in well #2 it is 280 ft asl. The qualitative interpretations of the S.P. data indicates the potential areas of increased ground water flow, or decreased depth to water table, occurs near well 3 which has the higher static water level. This well data, coupled with the qualitative S.P. interpretation, suggests that there is likely little ground water flow between well locations 3 and 2 (from the south to north).

5.3.7 Hydrologic/Geologic Interpretation Summary (Keauhou Area)

The primary focus of the geophysical surveys at Keauhou was to test several geophysical methods to map a postulated, secondary ground water damming structure which has created large static water differences between two existing wells (wells #2 and #3). The initial hypothesis was that the ground water damming structure was caused by intrusive dikes between the wells. Because the Keauhou area is populated, there are significant cultural features (pipelines, power lines, fences, houses, etc.) located in the survey area. A secondary focus of the work was to determine which geophysical methods could be used effectively in this cultural environment. This objective has some importance, considering that future prospective areas for ground water exploration are becoming rapidly built up. The geophysical methods tested at Keauhou and their general susceptibility to cultural interferences are listed in Table 5-1.

Table 5-1
Geophysical methods used at Keauhou and their relative susceptibility to cultural interference

Method	Qualitative Susceptibility to Cultural Interference
TDEM soundings	Moderate susceptibility - poor data can be recognized, but not corrected
TDEM profiling	Moderate to high - poor data are recognized, but cannot be corrected
Gravity	Low to none - not affected for the most part
Magnetics	High - data are strongly influenced by all ferromagnetic materials and power lines
Self Potential	Low to moderate - data appear to be usable

From the one test line (Line 1) across the postulated structure, it is clear that the TDEM soundings and gravity data produce the most reliable results. The TDEM profiling did not detect any significant geologic targets in the test area. The magnetics were strongly affected by cultural noise sources, and the interpretation of the filtered data did not indicate a strong magnetic structure in the vicinity of the two wells. The S.P. data could only be interpreted in a qualitative sense and that interpretation needs to be tied to hydrologic information (pump tests, recharge rates, static water levels, etc.) to be of use.

The combined interpretation of the gravity and TDEM soundings on Line 1 is shown on Figure 5-23. These two methods are sensitive to different physical properties of earth materials. The gravity data detected two zones along the line where significant dense bodies are modeled. These zones are located between about station 0 and 1000N and between about 4750N and 5500N. These zones could represent intrusive dikes. As mentioned in Section 5.3.4.1, there is significant equivalence in the interpretation of the gravity data. In other words, the orientation of the bodies, the width, and to some degree the depth to the top of the bodies, can vary (probably by more than 200 ft) without affecting the match between the data and the model significantly.

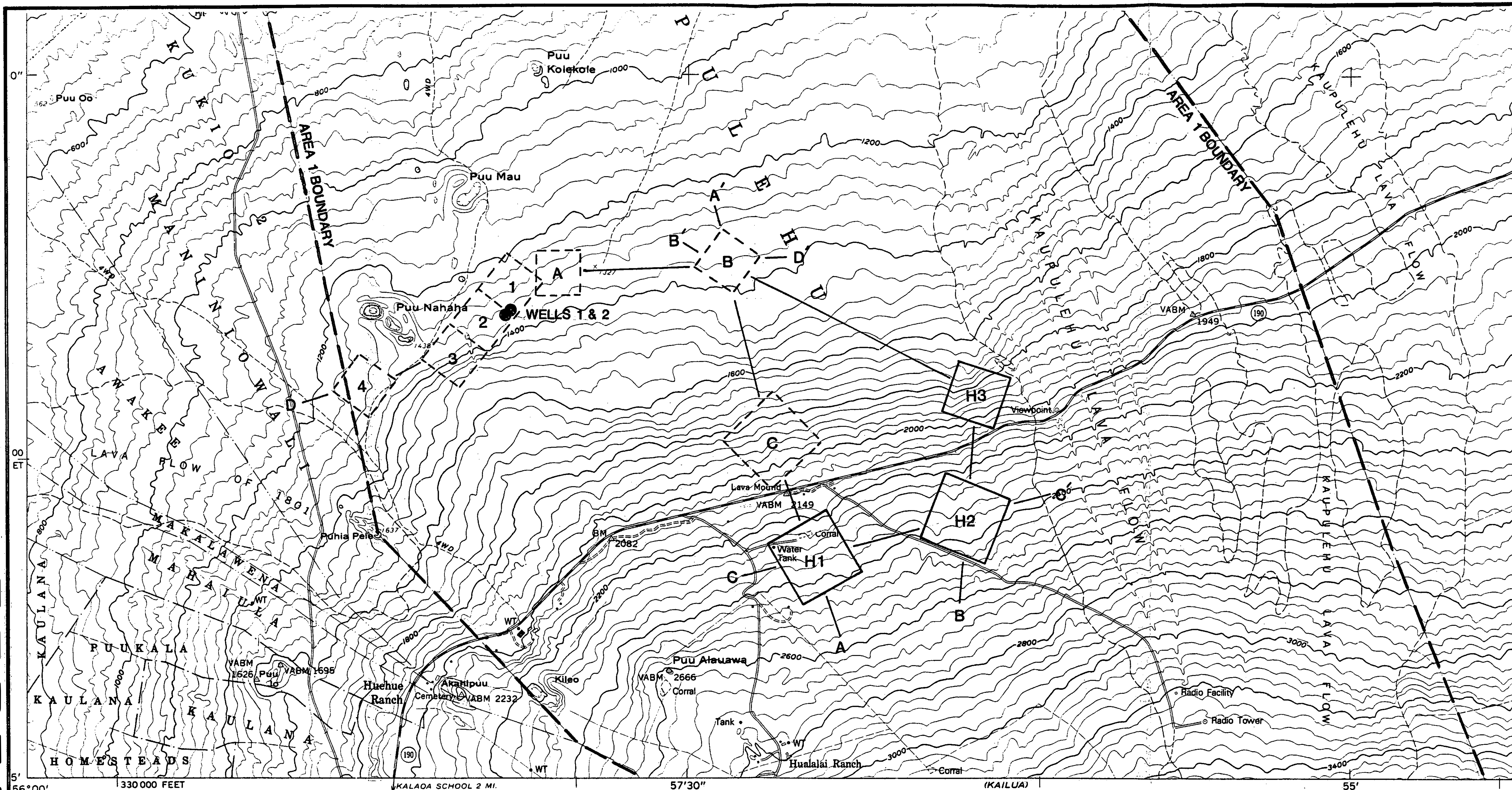
The TDEM sounding data is sensitive to resistivity variations. Two areas where significant changes in the geoelectric section are recognized correspond with the positions of anomalous gravity bodies. The corresponding TDEM and gravity anomalies between station 0 and 1250N is significant since here a geologic structure is postulated to exist. The orientation and position of the geologic structure is better resolved with the TDEM sounding.

Because of similar simultaneous occurrences of anomalies in the geoelectric section derived from TDEM soundings, and inferred from gravity data, exist between station 4750N and 5500N, a damming structure is postulated here as well. The TDEM soundings between 4750N and 5500N show the inferred structure to exist below sea level and so this section is different than that between the two wells. The gravity anomaly between 4750N and 5500N was modeled to a similar body as that between Wells 2 and 3. The gravity and TDEM data were not taken on exactly the same profile in this area (ref. Fig. 5-9), and on Figure 5-23 the gravity interpretation has been projected about 1,000 ft onto the TDEM profile. Figure 5-24 shows the anomalous zones detected in the TDEM soundings and gravity in plan view.

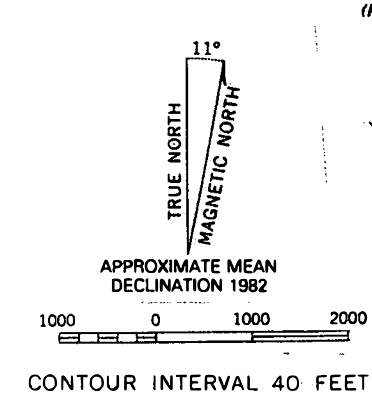
References

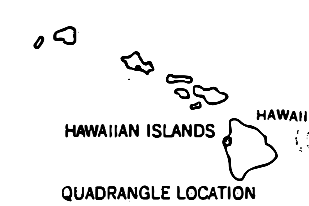
Hildenbrand, T.G., J. G. Rosenbaum, and J.P. Kauahikaua, 1993. Aeromagnetic study of the Island of Hawaii. Journal of Geophysical Research, Vol. 98, No. B3, pp. 4099-4119.

Wilt, M.J., 1991. Interpretation of time domain electromagnetic soundings near geological contacts, Ph.D. Thesis, Lawrence Berkeley Laboratory, University of California Earth Sciences Division, 185 pp.



H1	TDEM Soundings (1993)
C (dashed)	Previous TDEM Soundings (1990)
A – A′	Section Line
●	Well Location



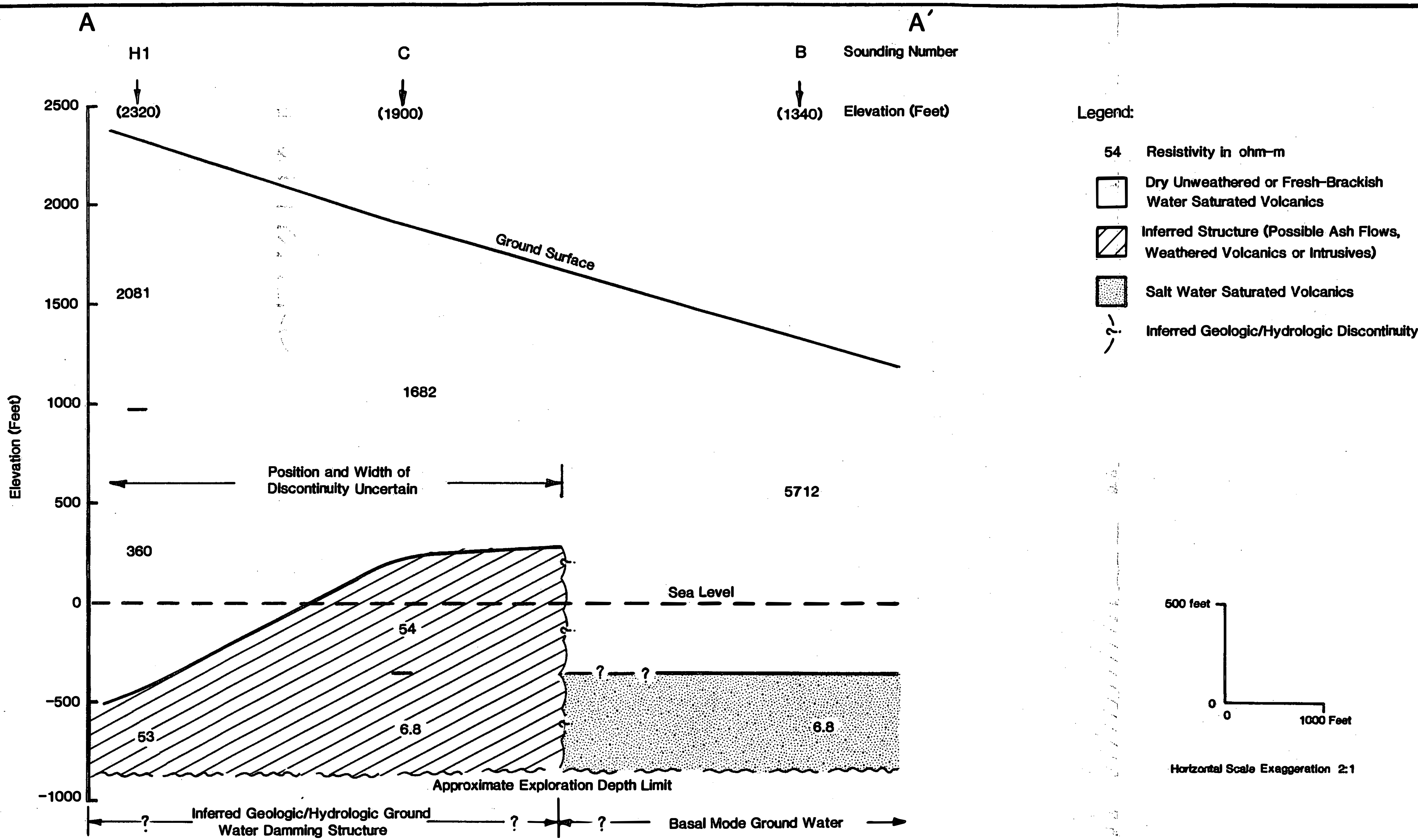


KIHOLO QUADRANGLE

CEES BLACKHAWK GEOSCIENCES DIVISION

LOCATION MAP
KAUPULEHU PROJECT-AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

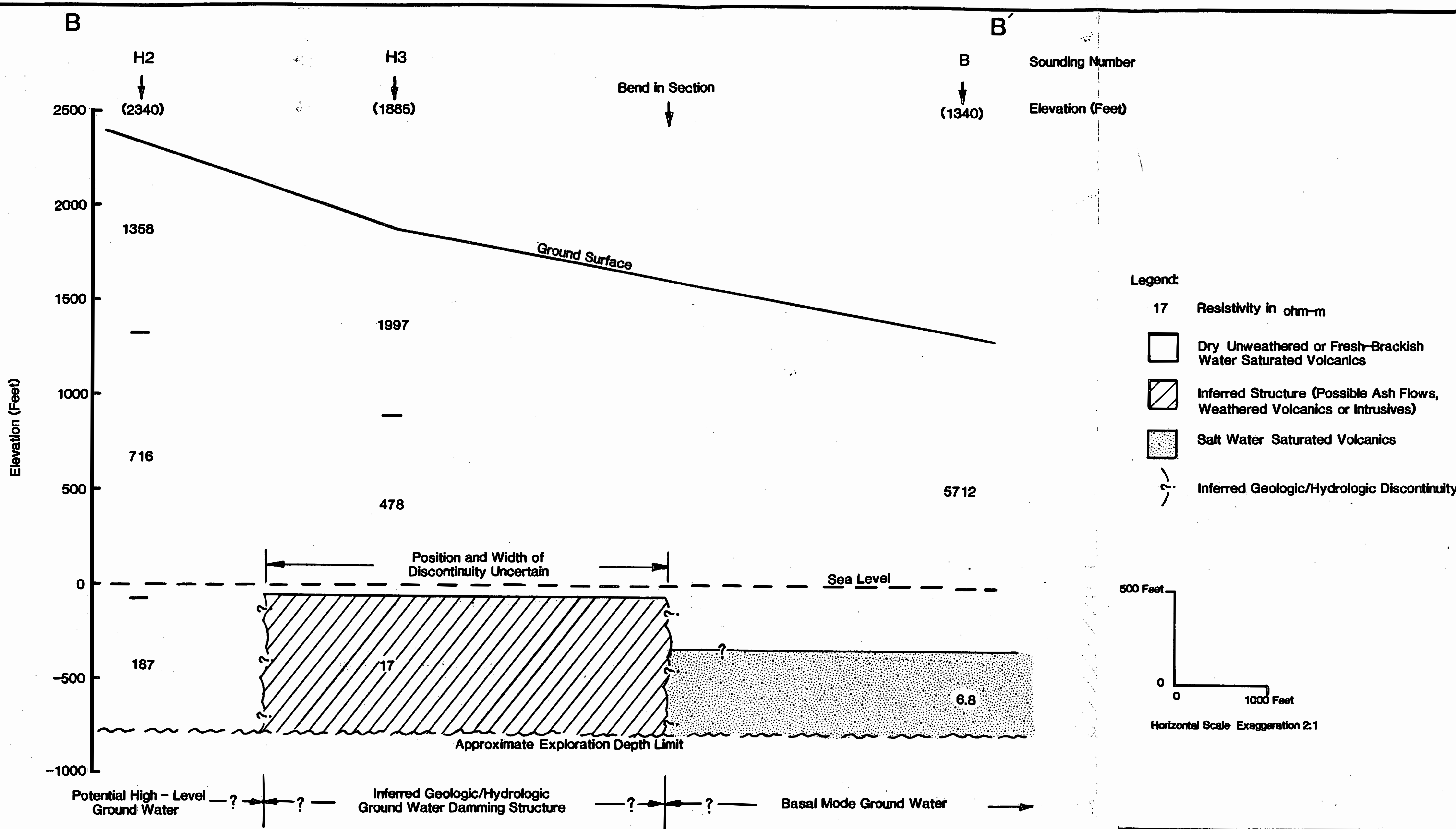
PROJECT NO. 9038 Figure 5-1



CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION
A – A′
KAUPULEHU PROJECT – AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

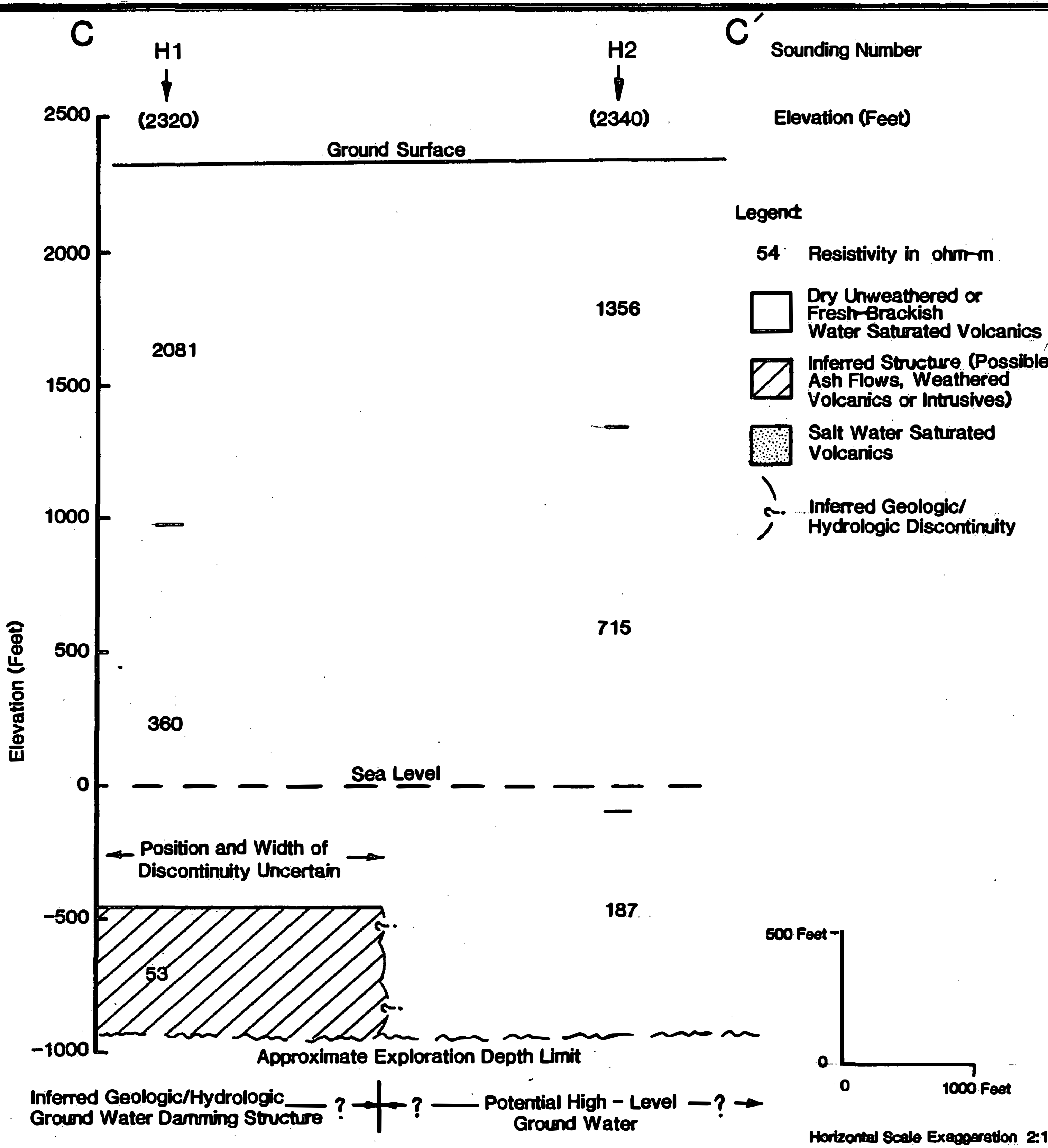
PROJECT NO. 9038 FIGURE 5-2



CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION
B - B´
KAUPULEHU PROJECT - AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-3

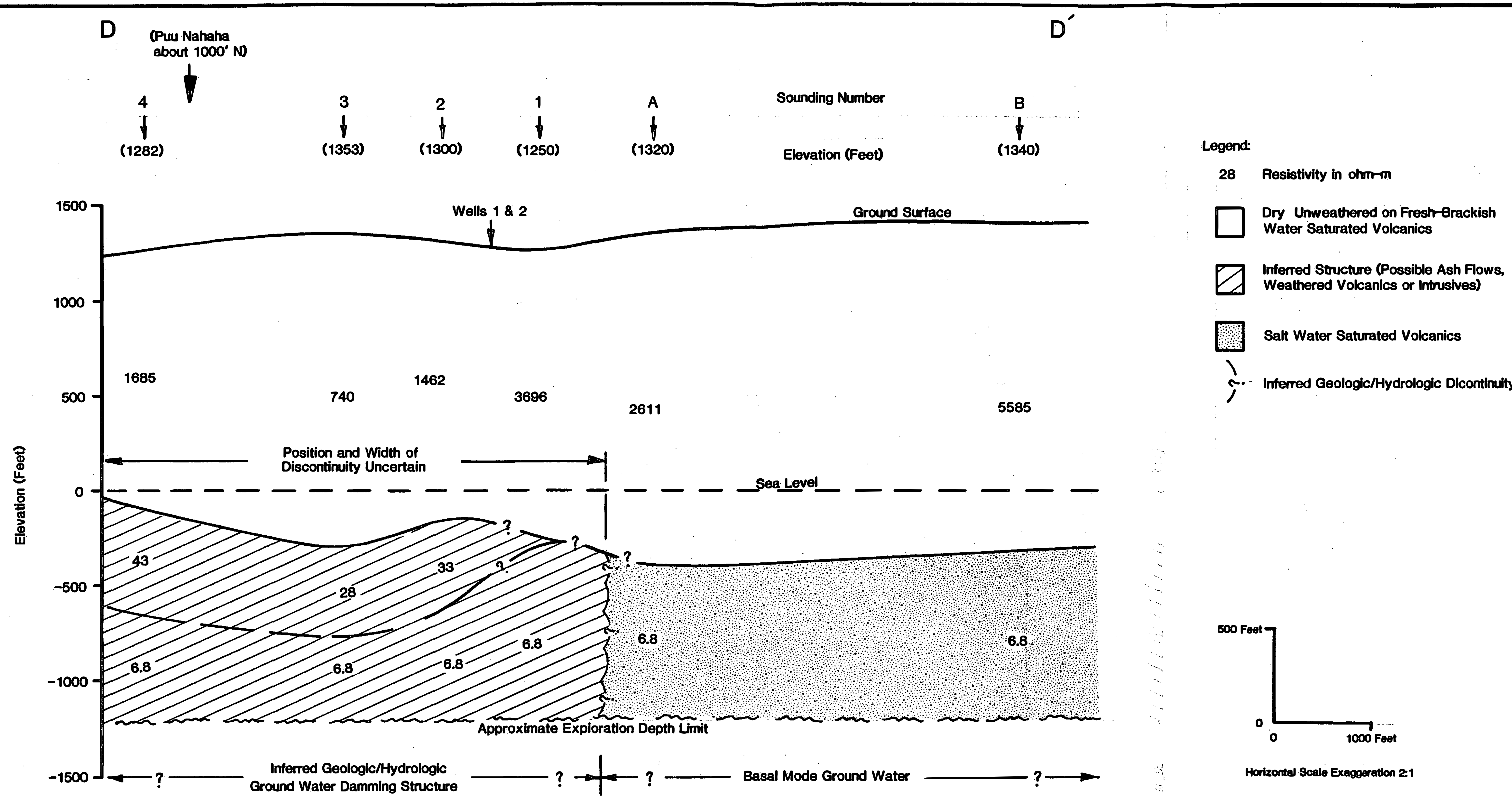


CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION
C – C′

KAUPULEHU PROJECT – AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

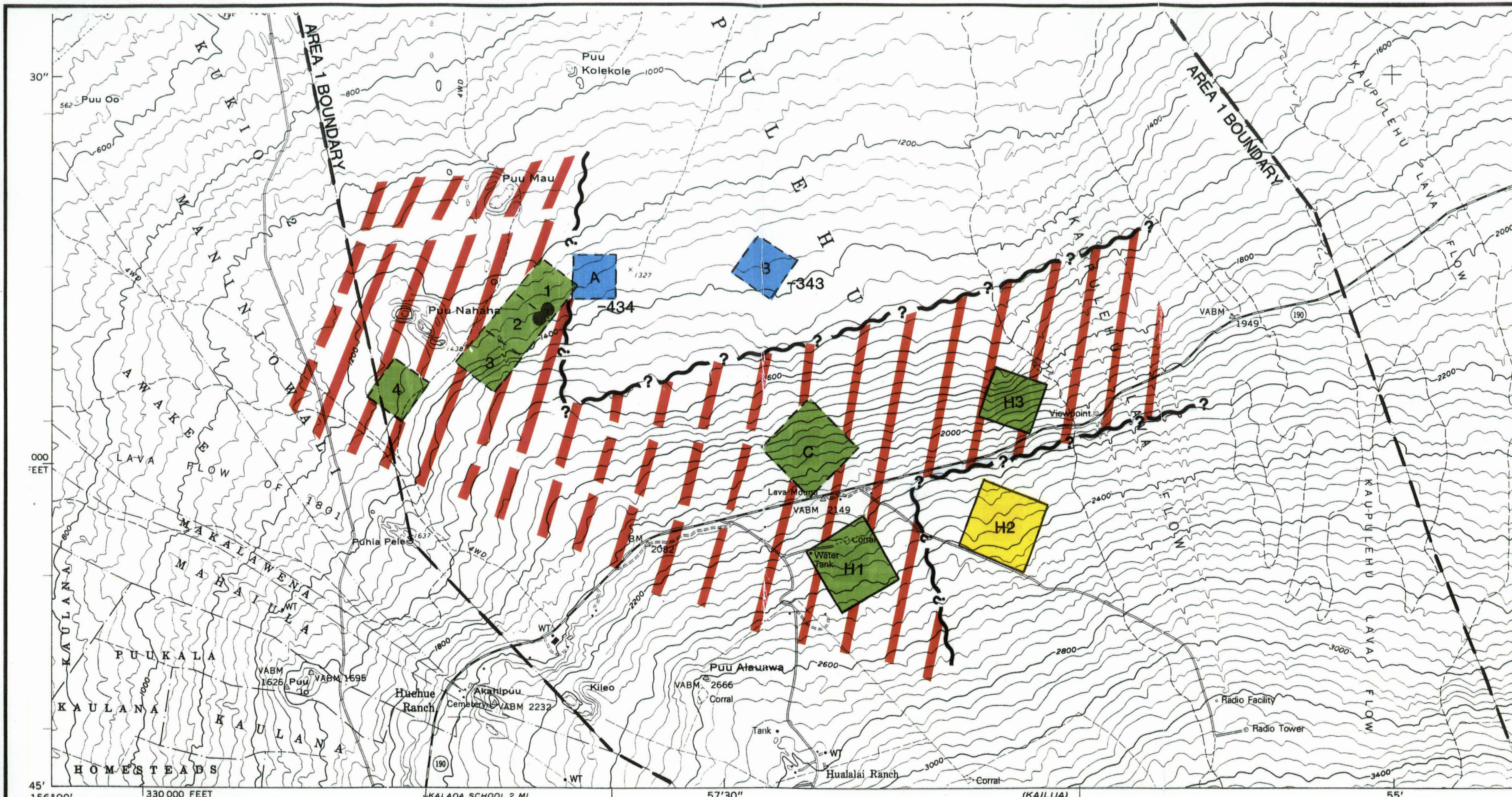
PROJECT NO. 9038 FIGURE 5-4



CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION
D – D´
KAUPULEHU PROJECT – AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-5



Well Location

-343 Approximate Elevation of Top of Salt Water Interface in Feet

Inferred Geologic/Hydrologic Discontinuity (Position Uncertain)

Sounding in Which Ground Water is Expected in Basal Mode

Sounding Interpreted to be Located Within Ground Water Barrier Zone

Sounding in Which Ground Water is Expected to be Controlled by Geologic Structures (Potential High - Level Water)

TRUE NORTH / MAGNETIC NORTH 11°

APPROXIMATE MEAN DECLINATION 1982

1000 0 1000 2000 Feet

CONTOUR INTERVAL 40 FEET

HAWAIIAN ISLANDS — HAWAII

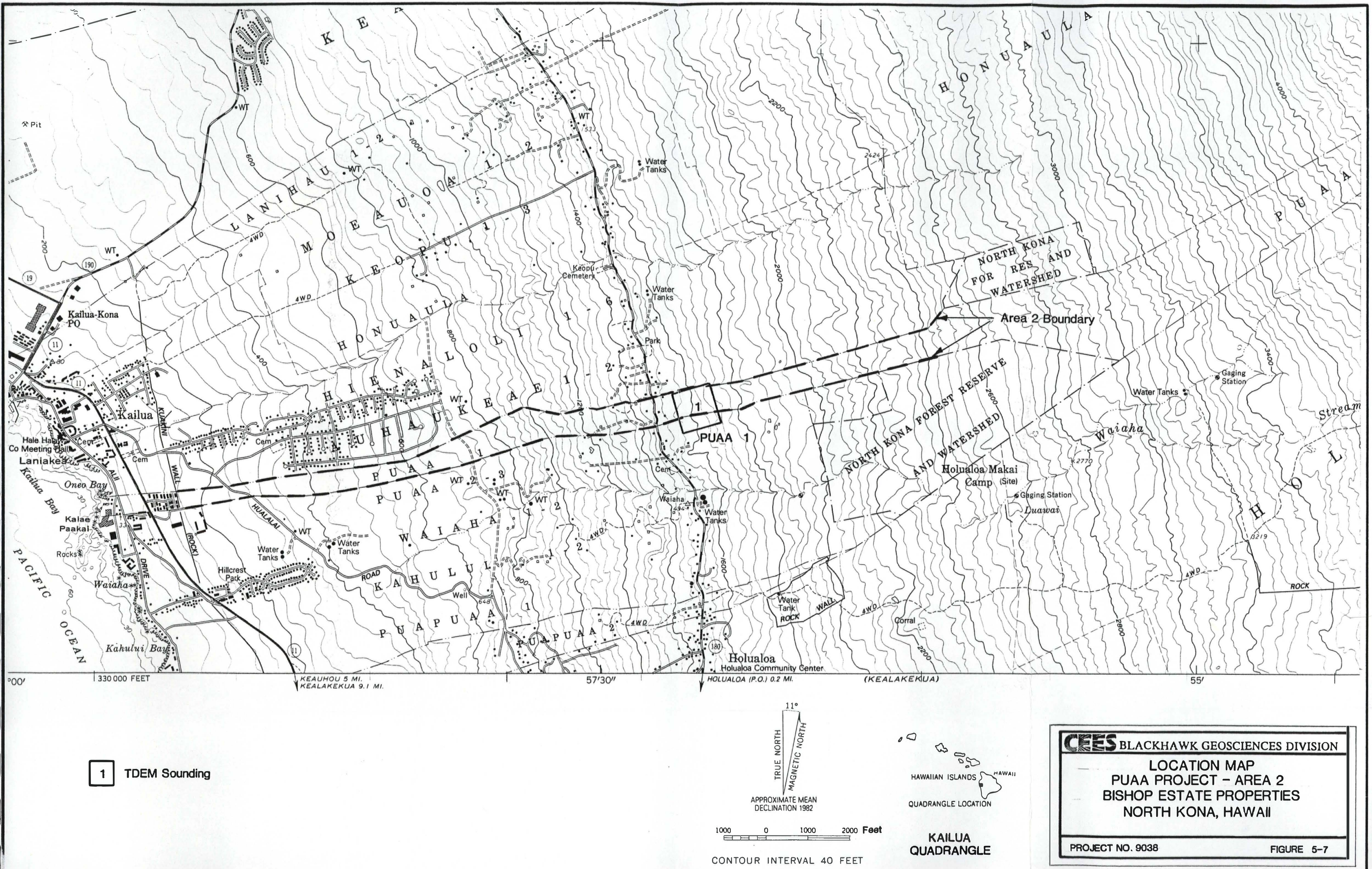
QUADRANGLE LOCATION

KIHOLO QUADRANGLE

CEES BLACKHAWK GEOSCIENCES DIVISION

GEOPHYSICAL INTERPRETATION SUMMARY MAP
KAUPULEHU PROJECT - AREA 1
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-6



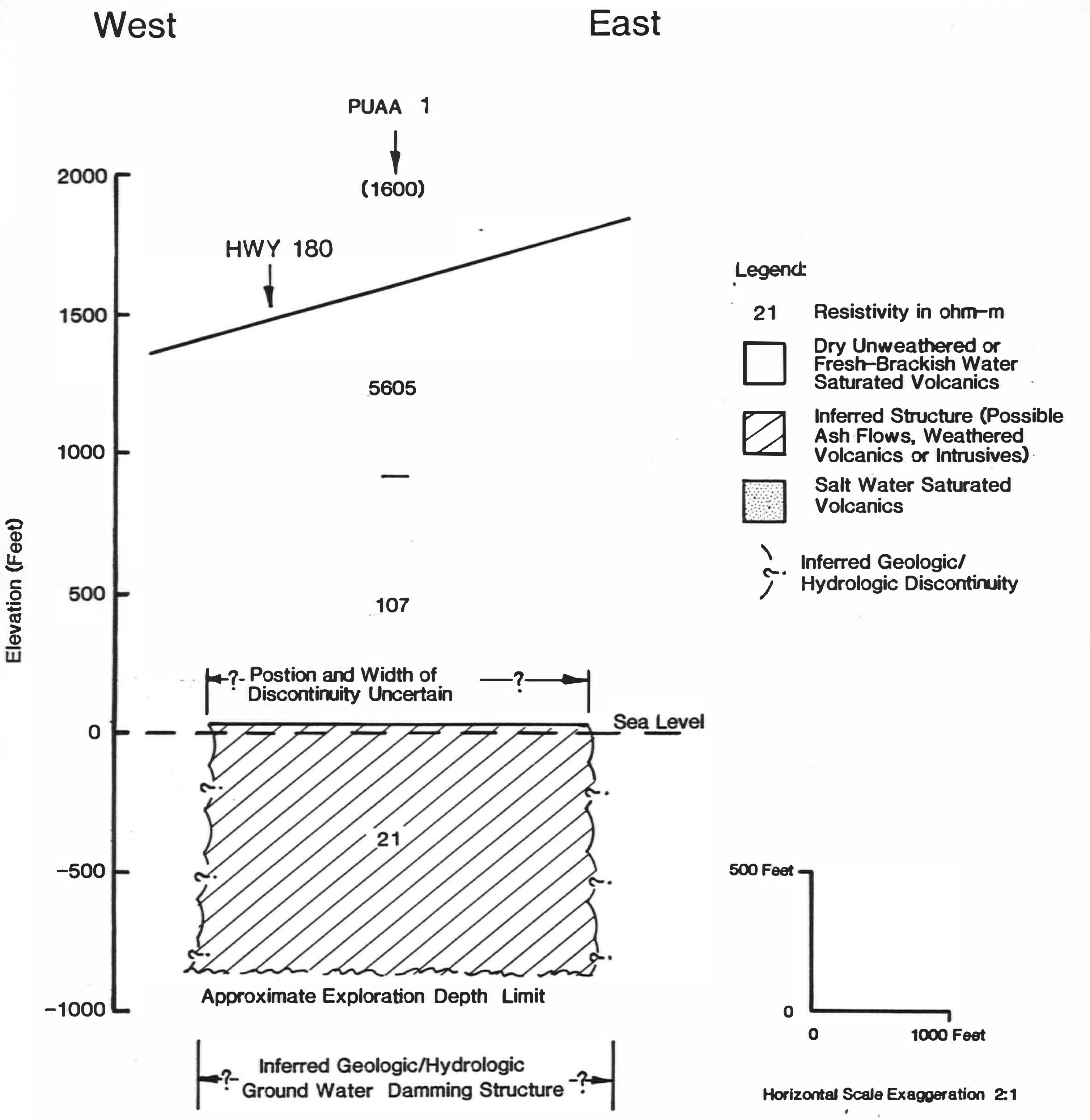
1 TDEM Sounding

CEES BLACKHAWK GEOSCIENCES DIVISION

LOCATION MAP
PUAA PROJECT - AREA 2
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038

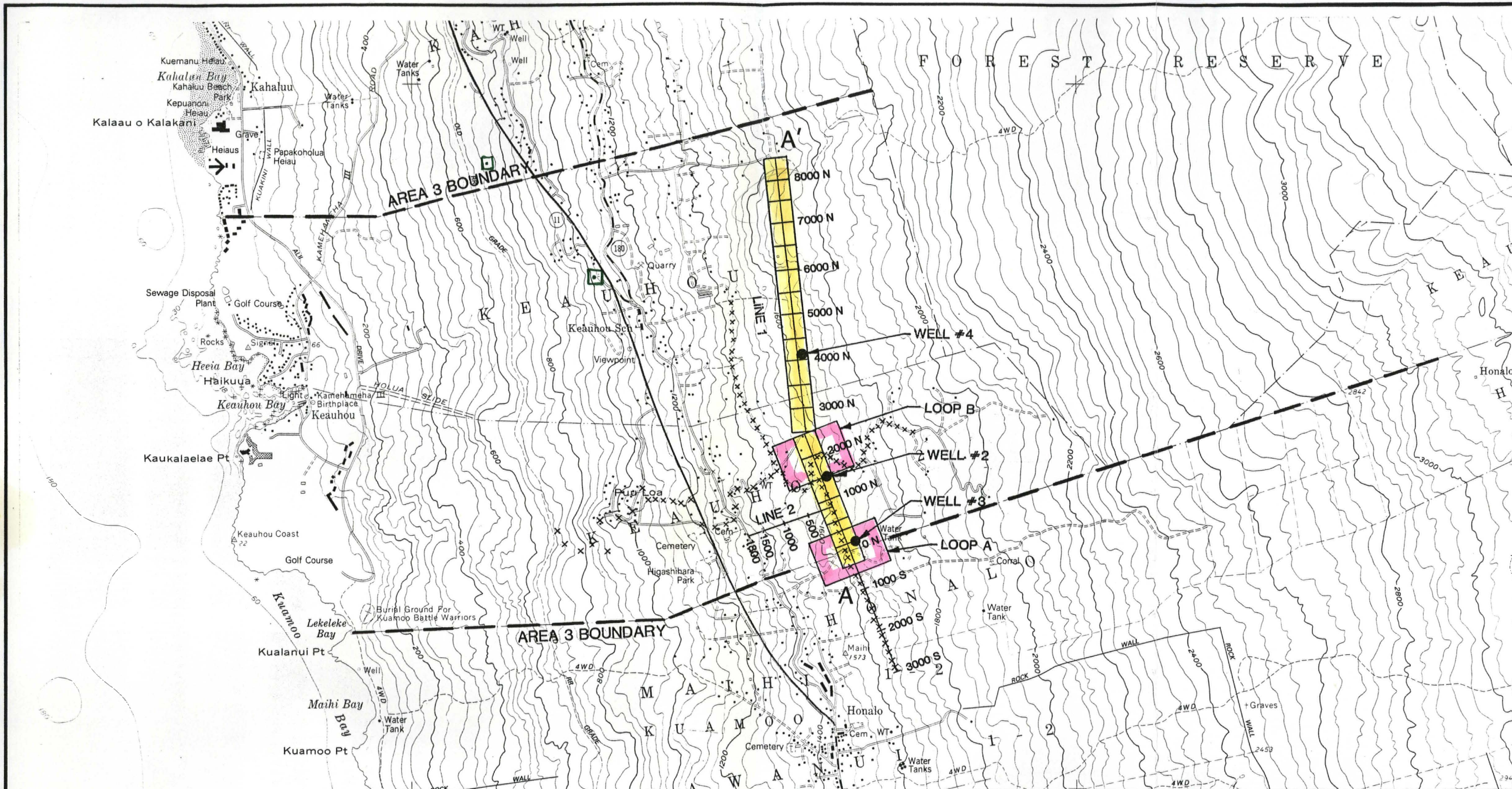
FIGURE 5-7



CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION
FROM TDEM INTERPRETATION
PUAA PROJECT - AREA 2
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-8



500' x 500' TDEM Sounding Loop

1000' x 1500' TDEM Profile Transmitter Loop

A – A' Section Line

● Well Location

X Gravity Stations

11°

TRUE NORTH

MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION 1982

1000 0 1000 2000 Feet

CONTOUR INTERVAL 40 FEET

HAWAIIAN ISLANDS

HAWAII

QUADRANGLE LOCATION

KEALAKEKAUA QUADRANGLE

CEES BLACKHAWK GEOSCIENCES DIVISION

LOCATION MAP

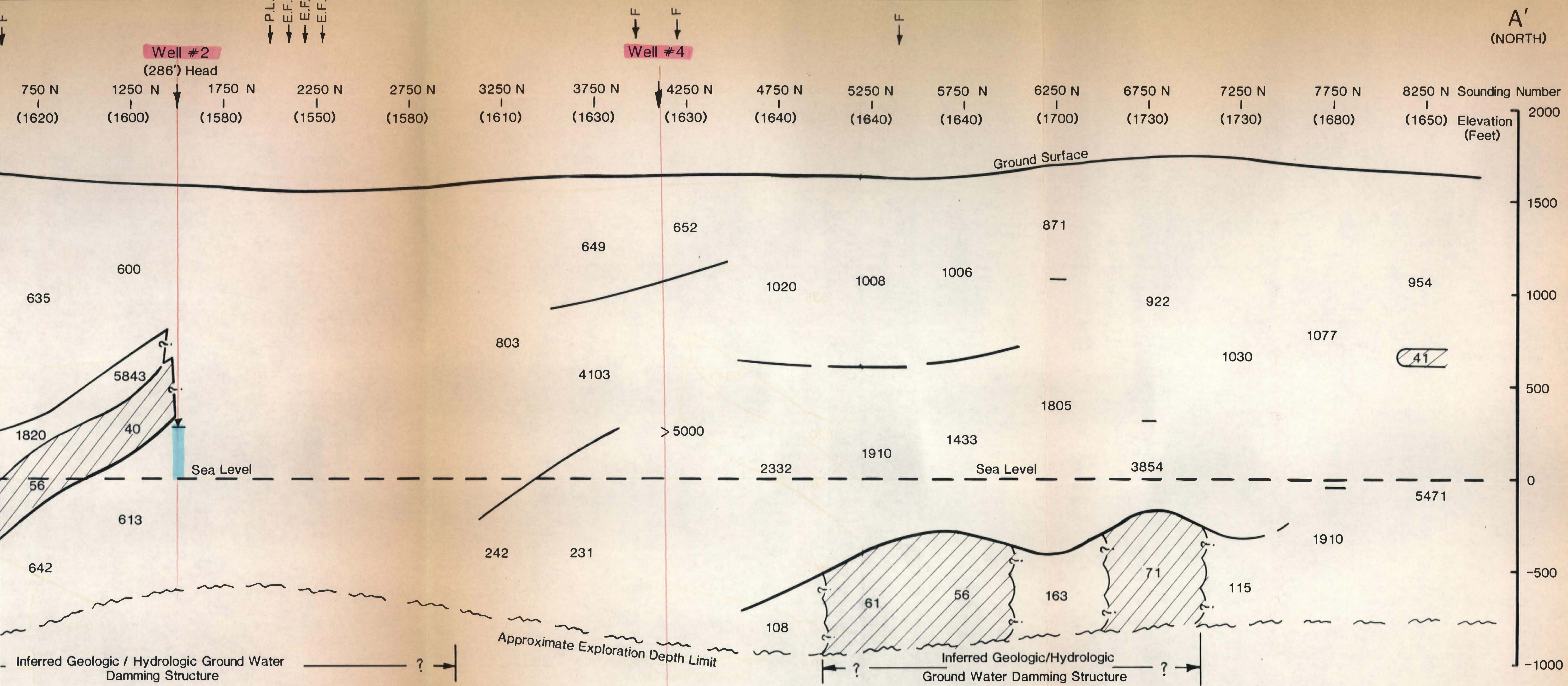
KEAUHOU PROJECT – AREA 3

BISHOP ESTATE PROPERTIES

NORTH KONA, HAWAII

PROJECT NO. 9038

FIGURE 5-9



weathered or Fresh–Brackish Water Saturated Volcanics

l Structure (Possible Ash Flows, Weathered Volcanics or Intrusives)

vity in ohm–m

l Goelogic/Hydrologic Discontinuity

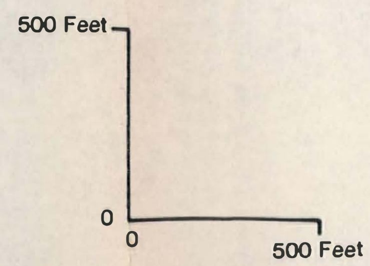
Water Level (Head) in Existing Well

CULTURAL OBJECTS:

P.L. Power Line

F Fence

E.F. Electric Fence



CEES BLACKHAWK GEOSCIENCES DIVISION

GEOELECTRIC CROSS SECTION

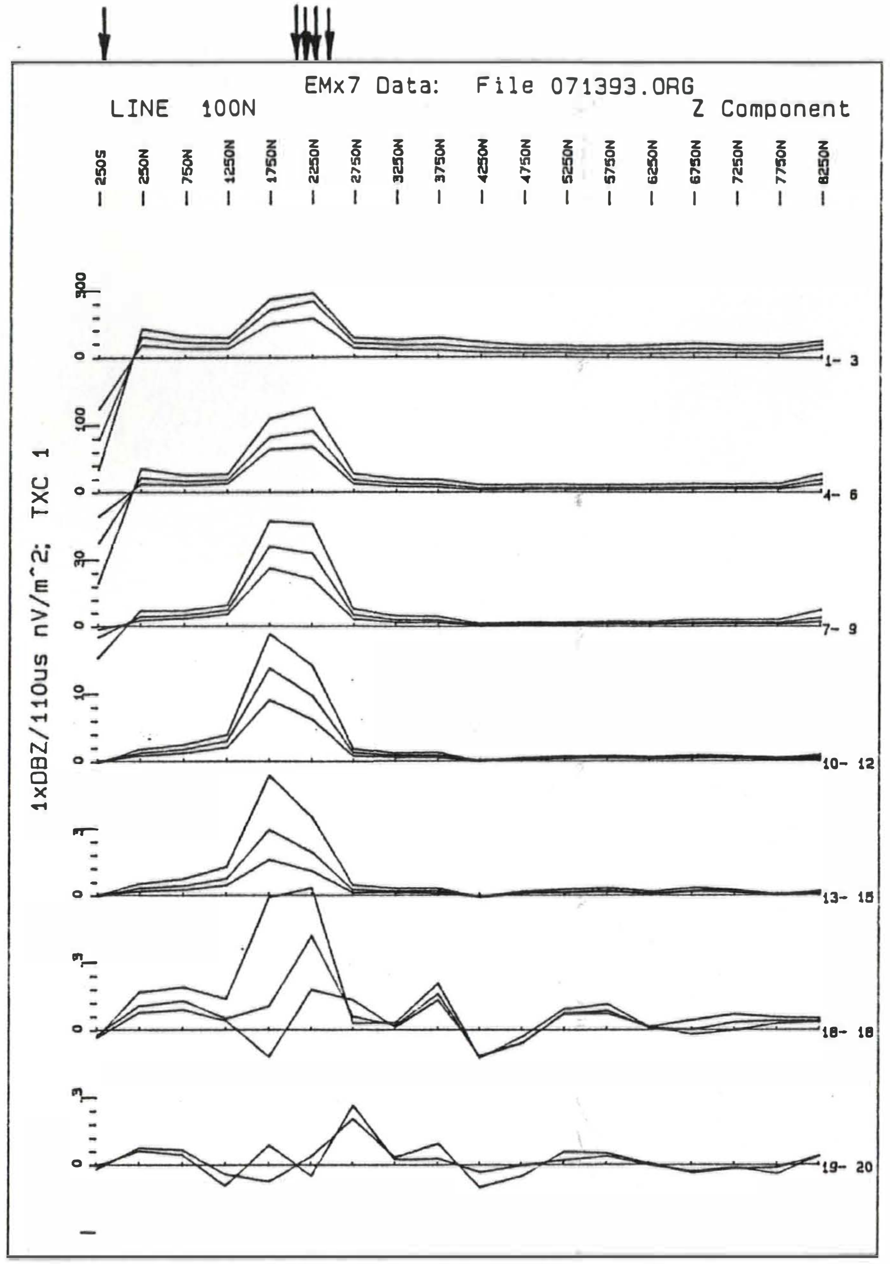
LINE 1 A – A′

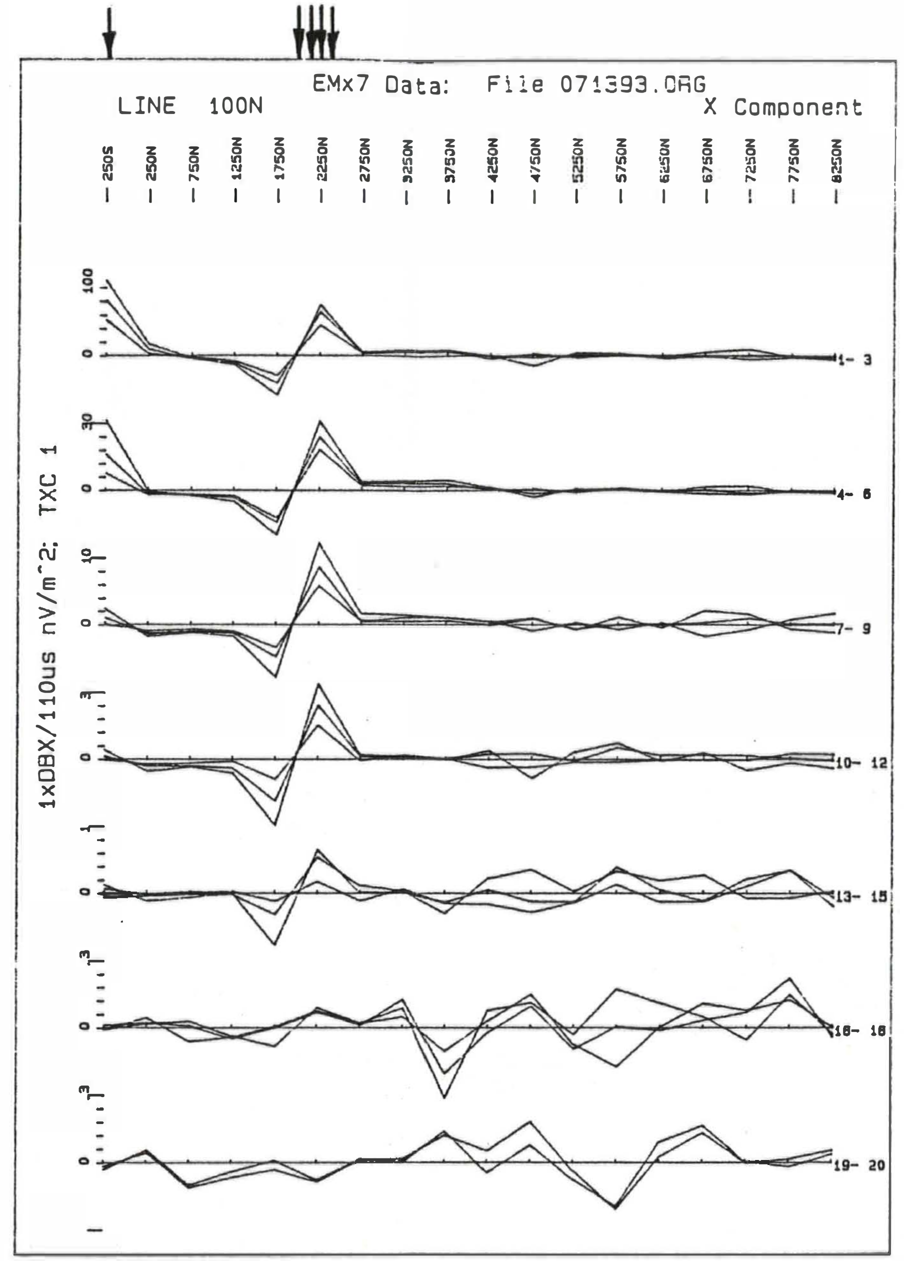
KEAUHOU PROJECT – AREA 3

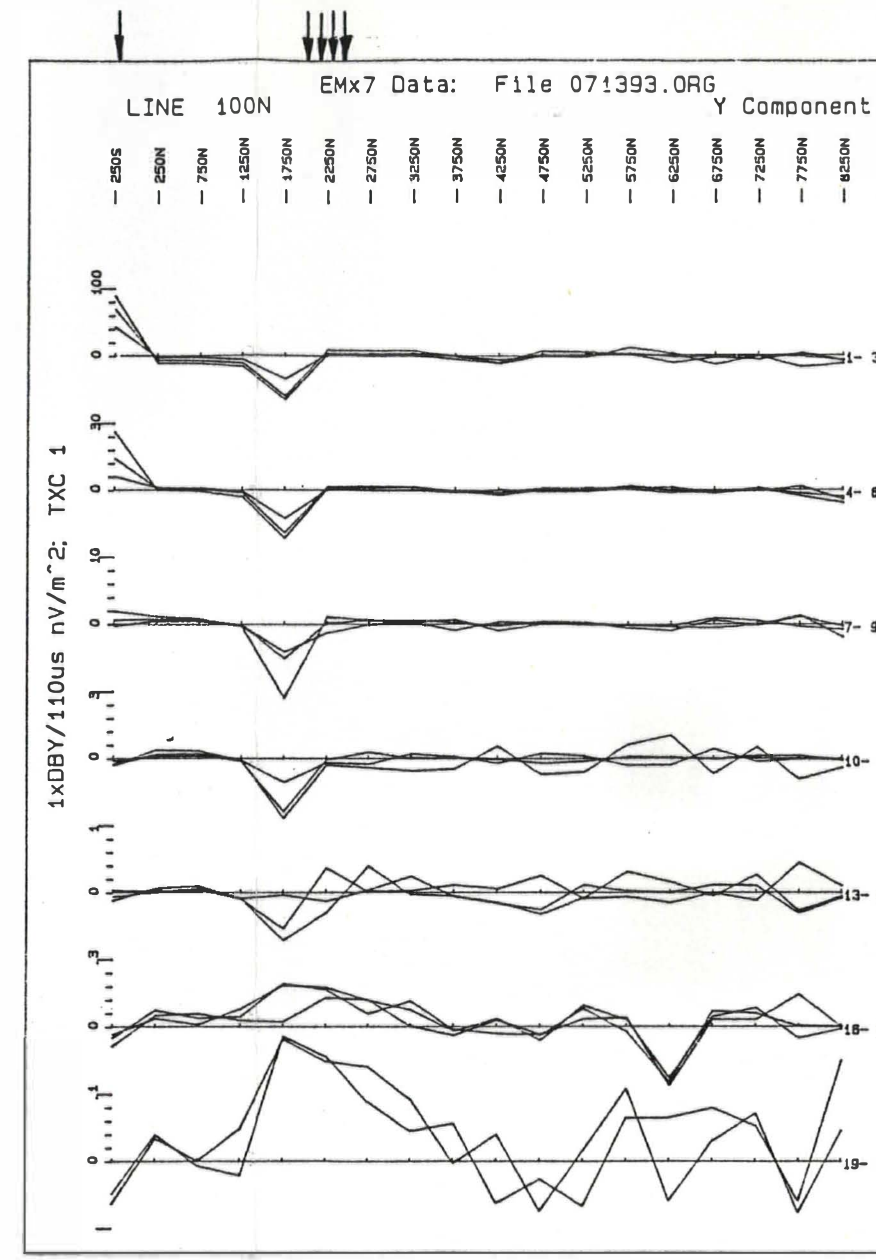
BISHOP ESTATE PROPERTIES

NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-10





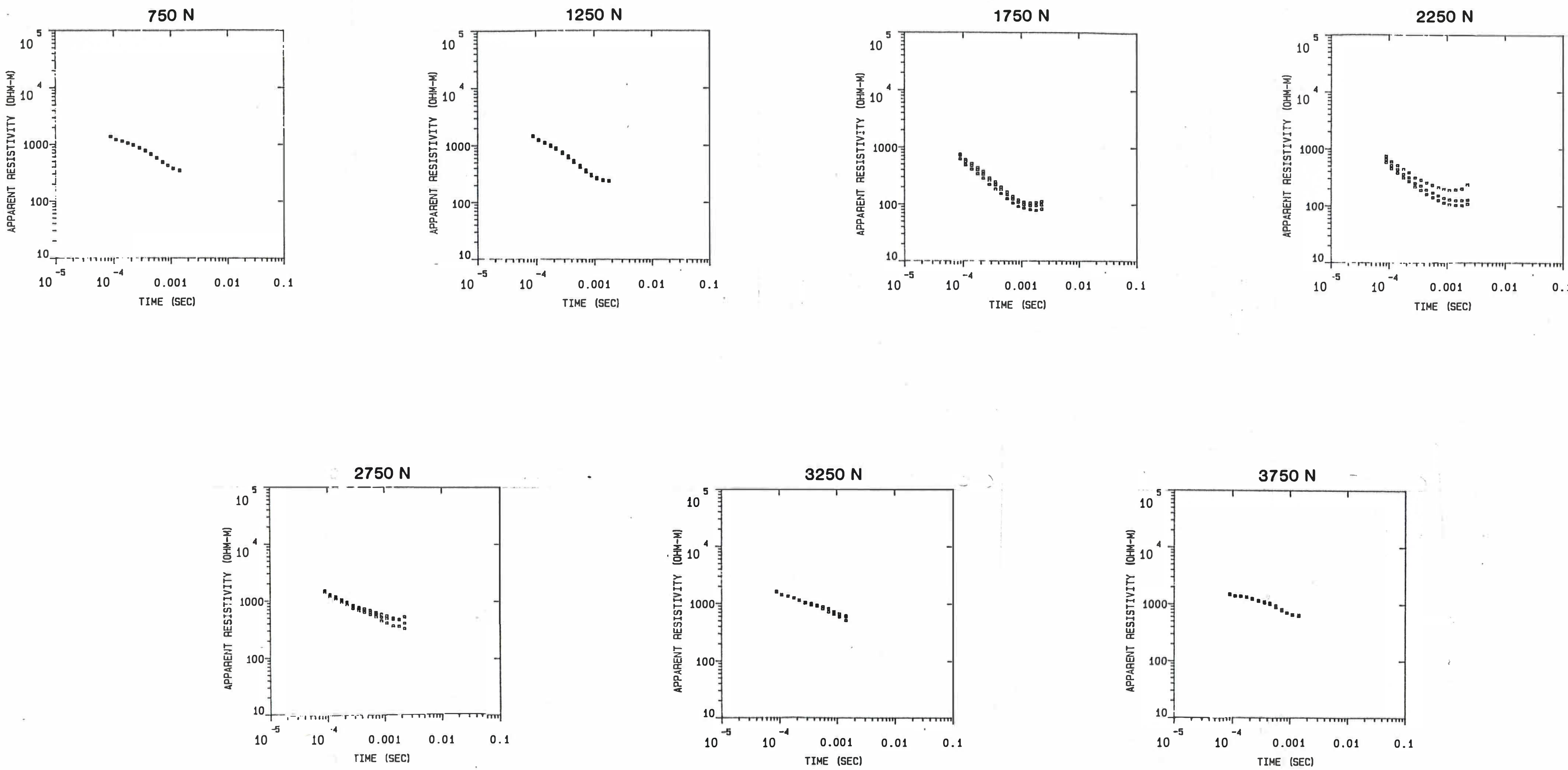


↓ Location of Powerlines and Fences

CEES BLACKHAWK GEOSCIENCES DIVISION

PLOTS OF FIELD COMPONENTS
(Z, X, Y) (500' x 500')
CENTER LOOP MEASUREMENTS - LINE 1
KAUPULEHAU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

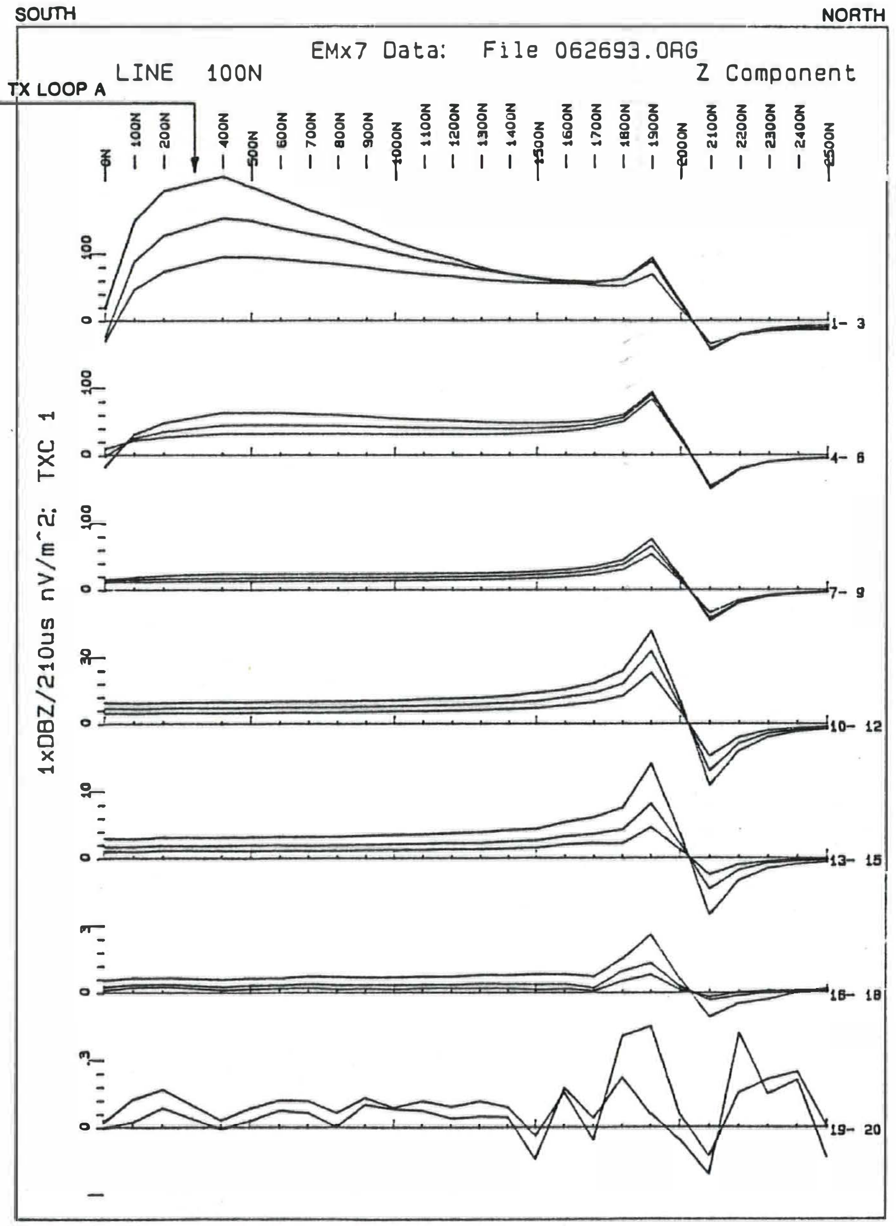
PROJECT NO. 9038 FIGURE 5-11

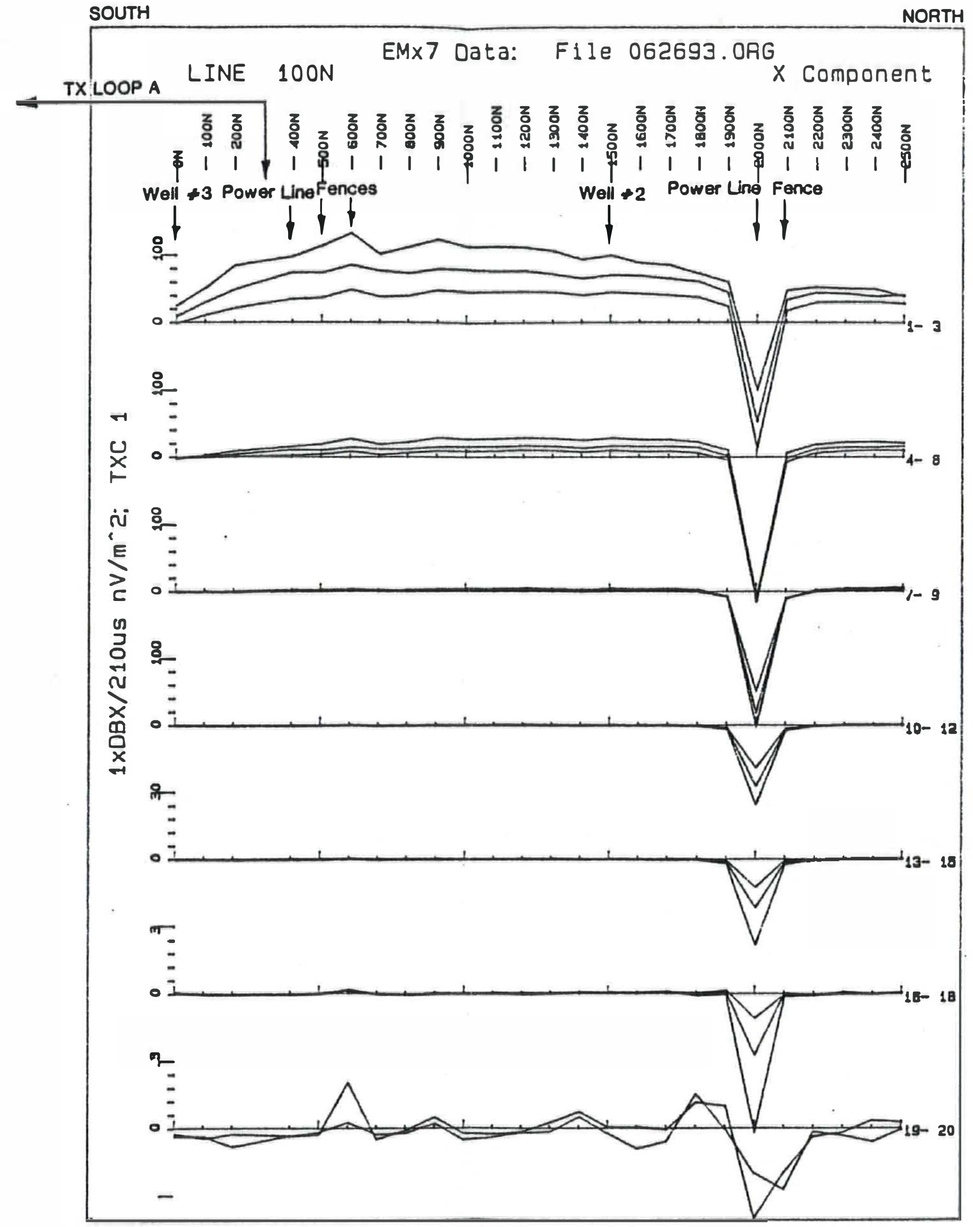


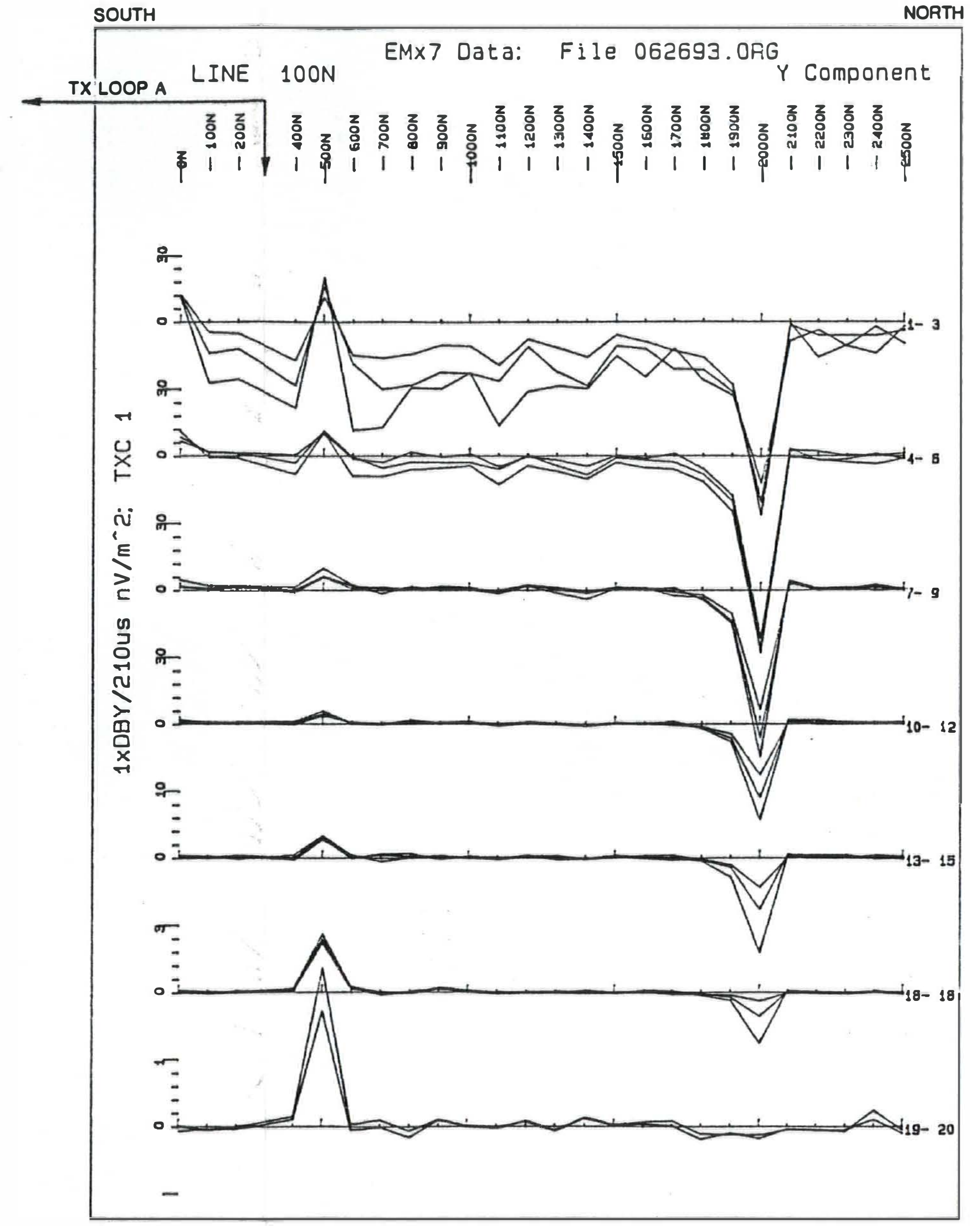
CEES BLACKHAWK GEOSCIENCES DIVISION

COMPARISON OF CENTRAL LOOP & 50' OFFSET POSTIONS FOR 500' x 500' LOOPS. LINE 1
KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA , HAWAII

PROJECT NO. 9038 | FIGURE 5-12





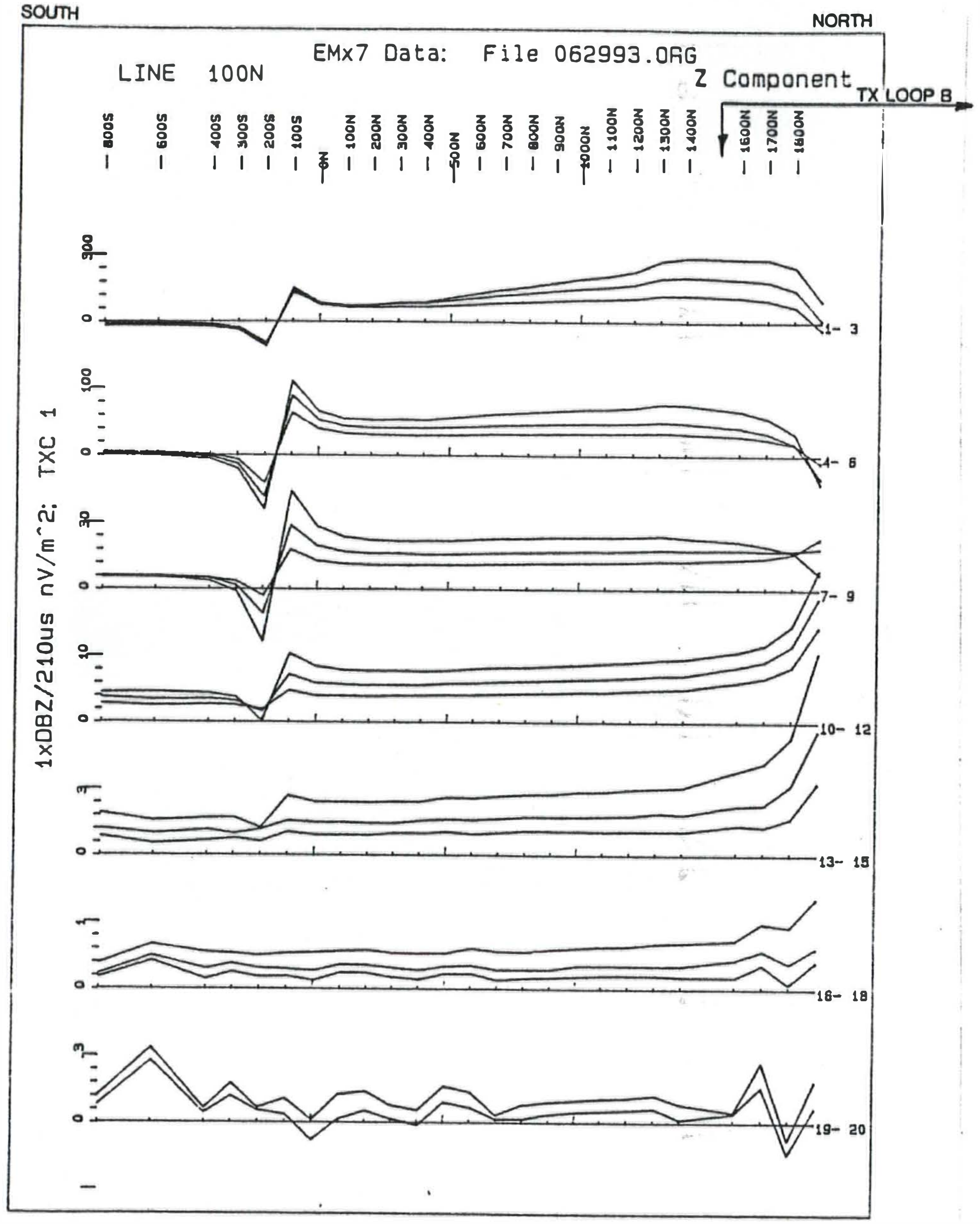


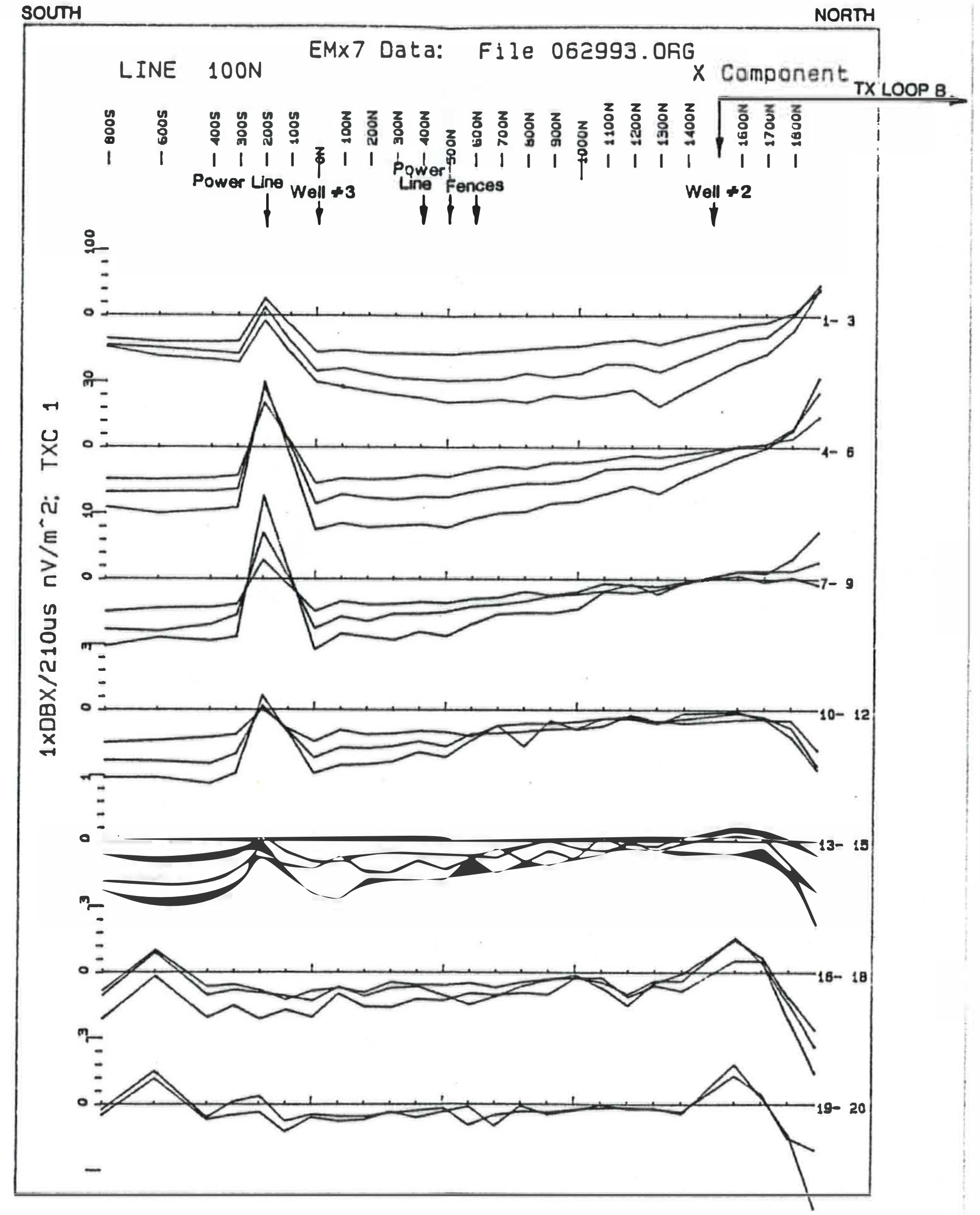
CEES BLACKHAWK GEOSCIENCES DIVISION

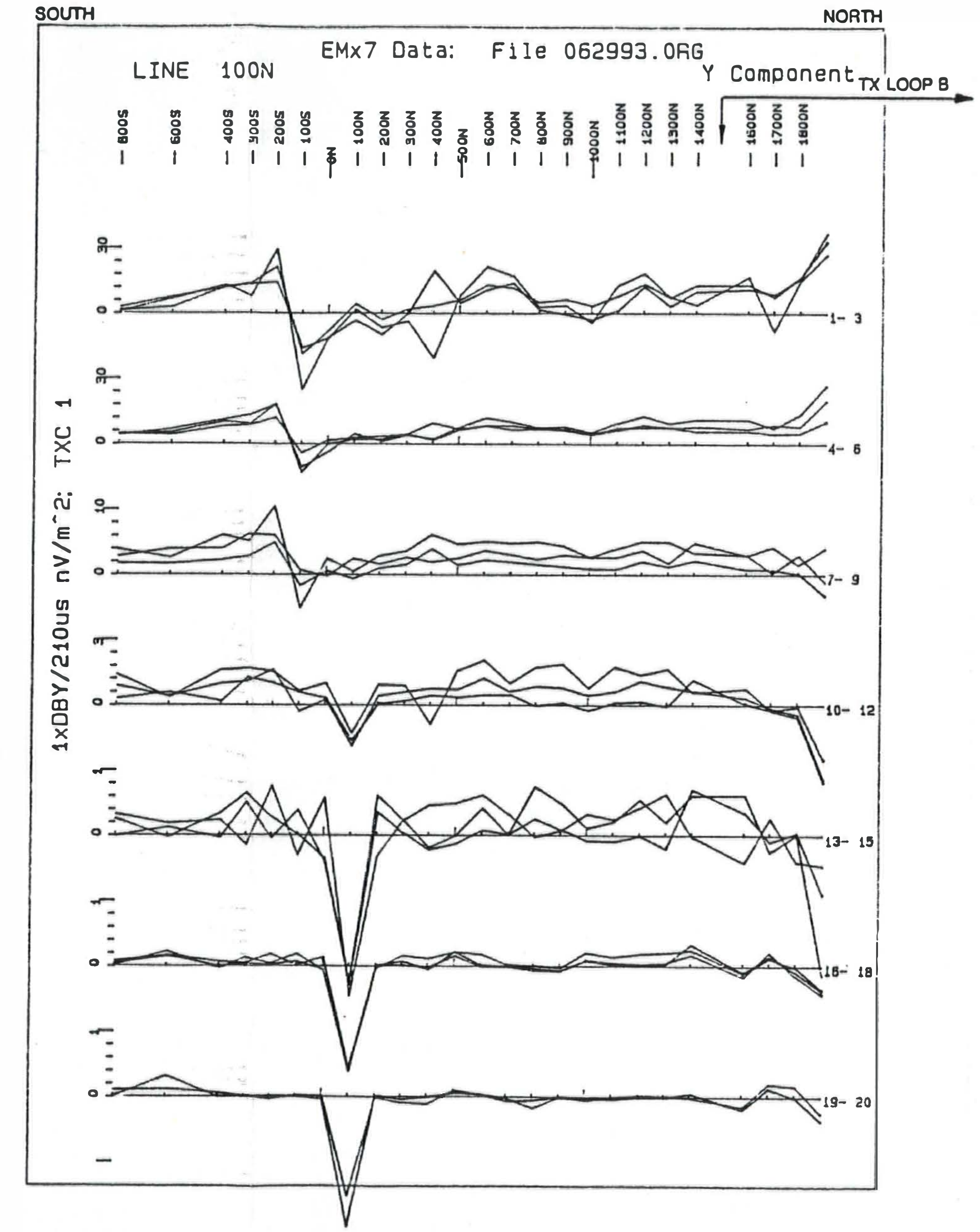
TDEM PROFILING DATA LINE 1 - LOOP A

KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-13







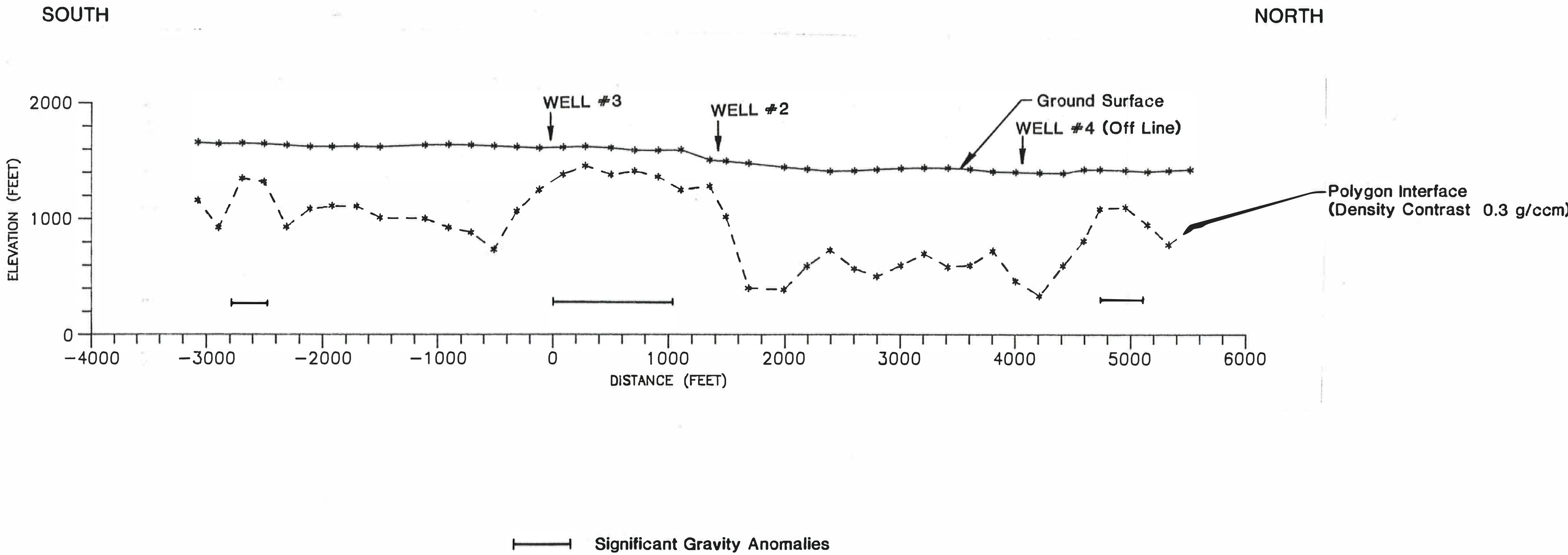
CEES BLACKHAWK GEOSCIENCES DIVISION

TDEM PROFILING DATA LINE 1 - LOOP B

KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038

FIGURE 5-14

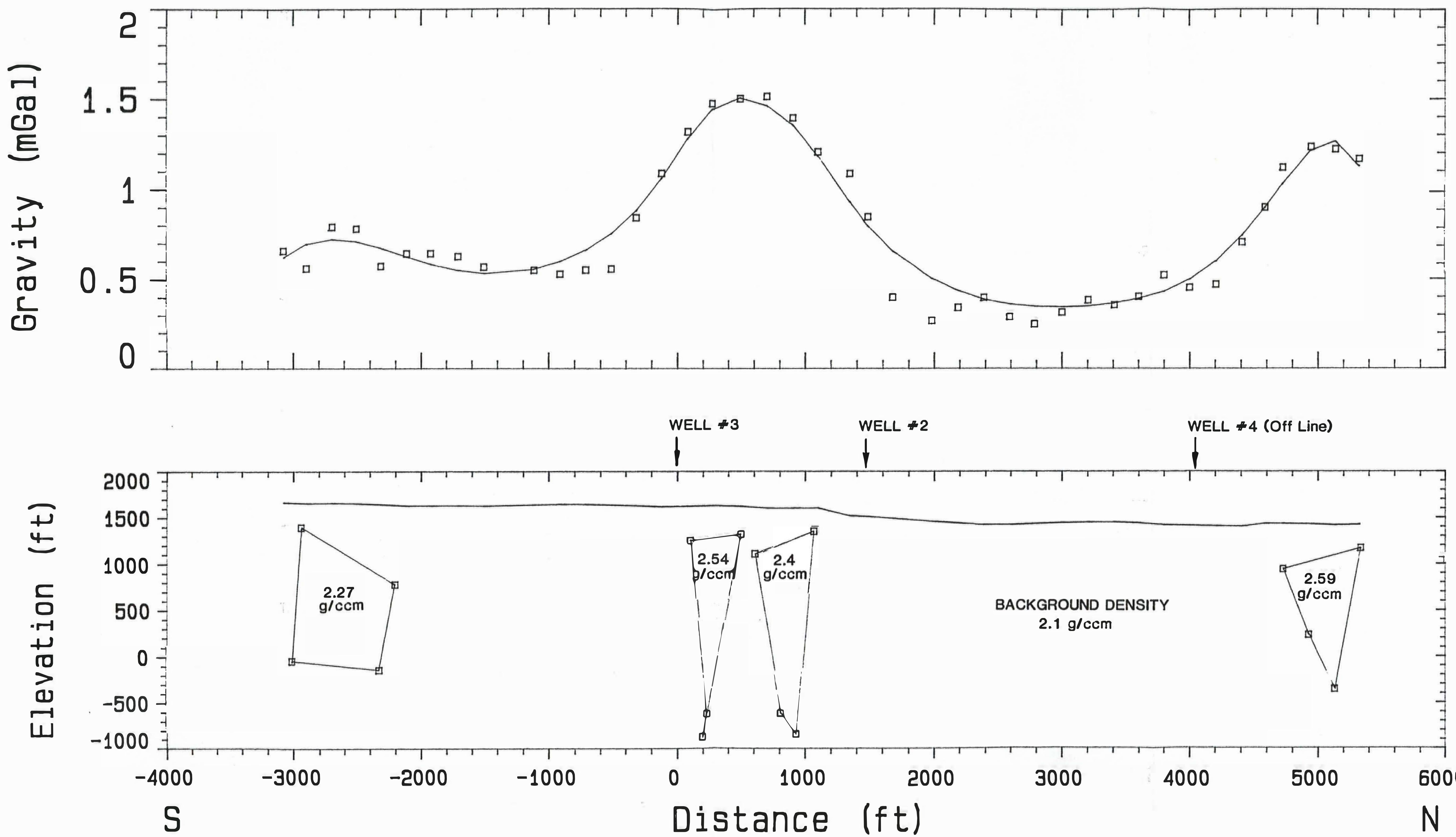


CEES BLACKHAWK GEOSCIENCES DIVISION

GRAVITY MODELING-LINE 1
INFINITE LONG HORIZONTAL POLYGON

BISHOP ESTATE PROPERTIES
KEAUHOU PROJECT - AREA 3
NORTH KONA, HAWAII

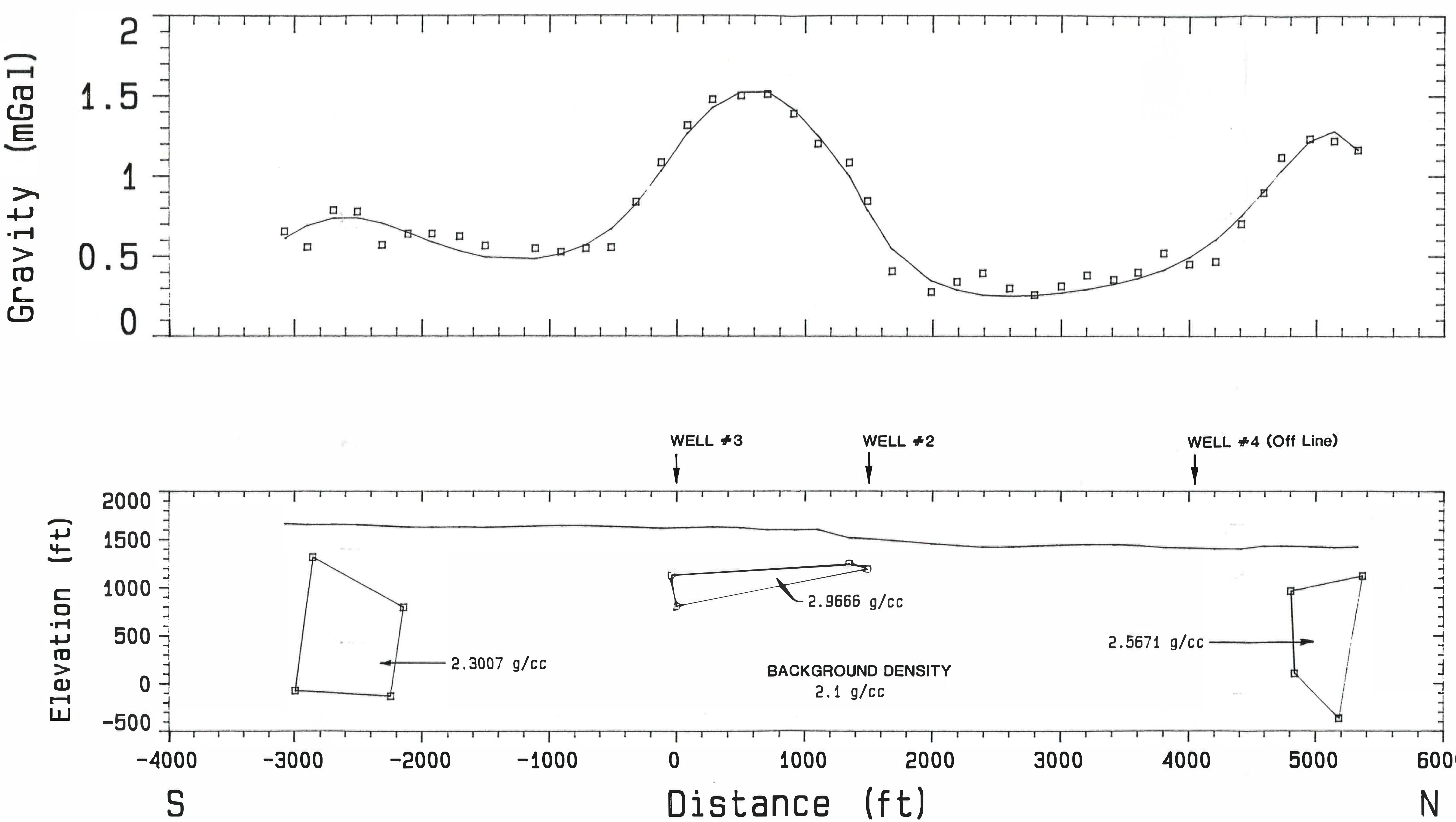
PROJECT NO. 9038 FIGURE 5-15



BISHOP ESTATES		ISLAND OF HAWAII
CEES BLACKHAWK GEOSCIENCES DIVISION		KEAUHOU NORTH KONA
Data Set: GRAV1	Date: AUG-93	
Scale: 1:9600	Profile: 100	Vertical Exaggeration: 0.72 : 1

PROJECT NO. 9038

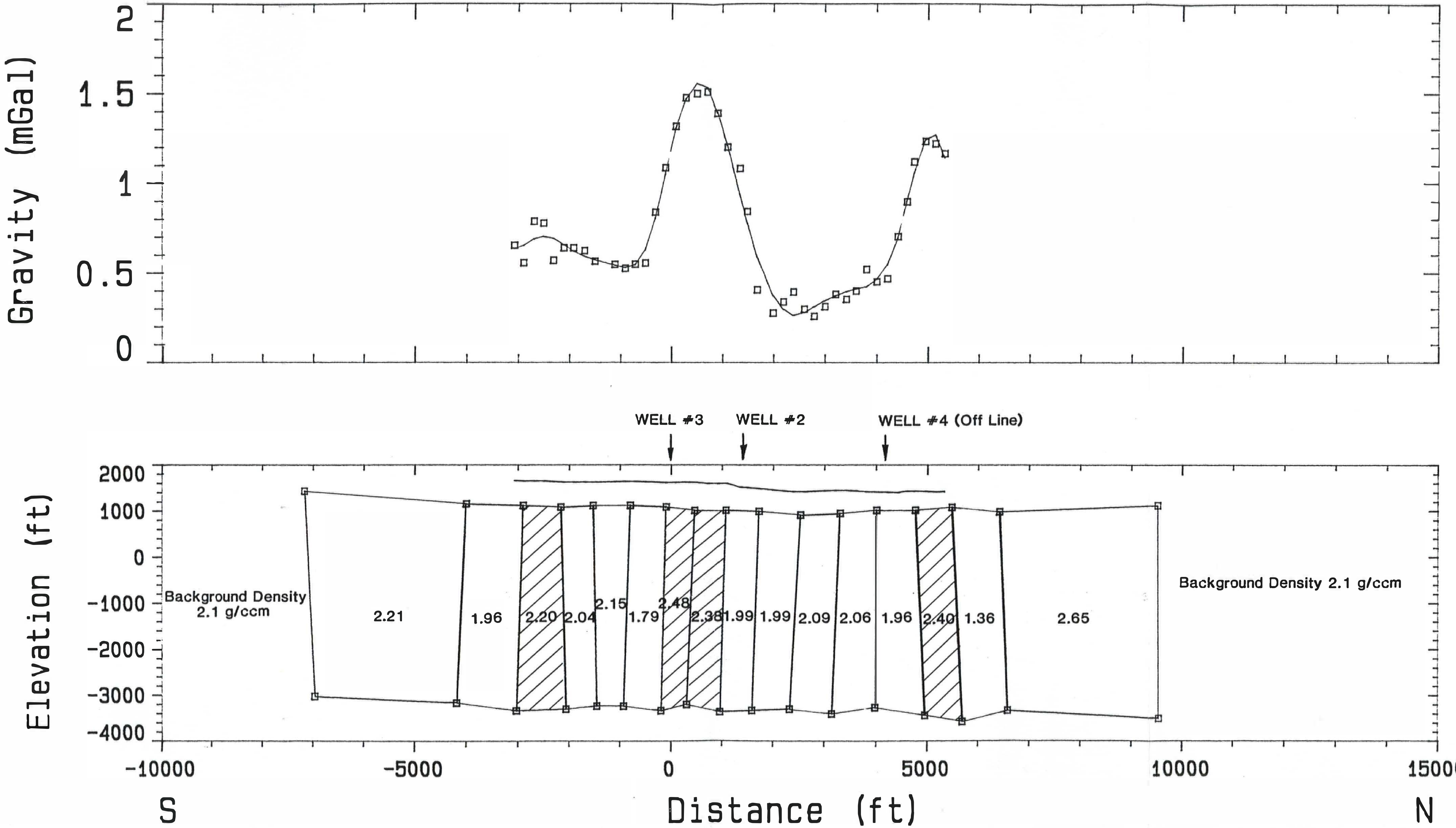
FIGURE 5-16



BISHOP ESTATES		ISALND OF HAWAII
CEES BLACKHAWK GEOSCIENCES DIVISION		KEAUHOU NORTH KONA
Data Set: L1G2	Date: AUG-93	
Scale: 1: 10000	Profile: 100	Vertical Exaggeration: 0.75 : 1

PROJECT NO. 9038

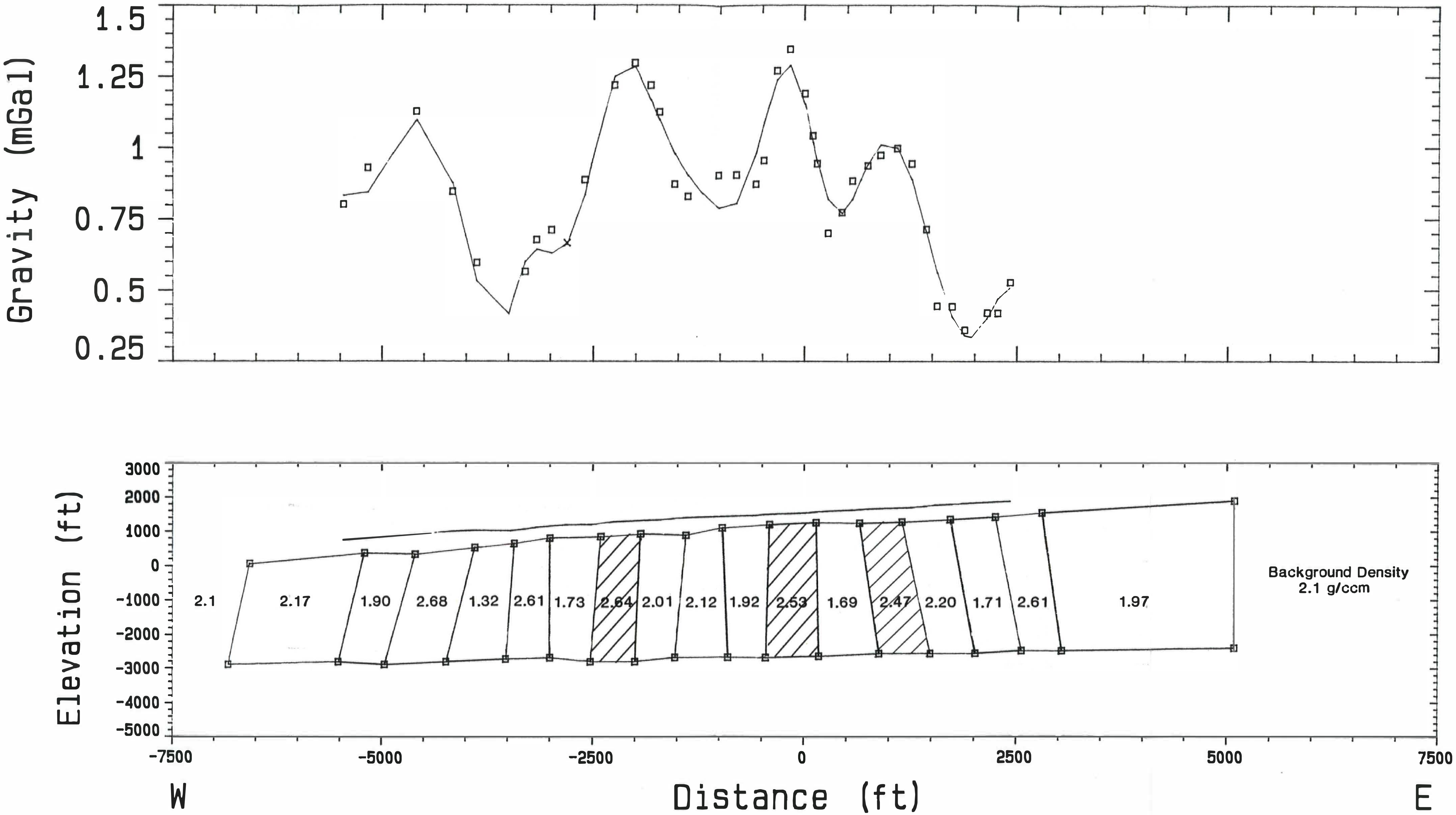
FIGURE 5-17



BISHOP ESTATES		ISLAND OF HAWAII
CEES BLACKHAWK GEOSCIENCES DIVISION		KEAUHOU NORTH KONA
Data Set: L1G3	Date: AUG-93	
Scale: 1: 24000	Profile: 100	Vertical Exaggeration: 0.90 : 1

PROJECT NO. 9038

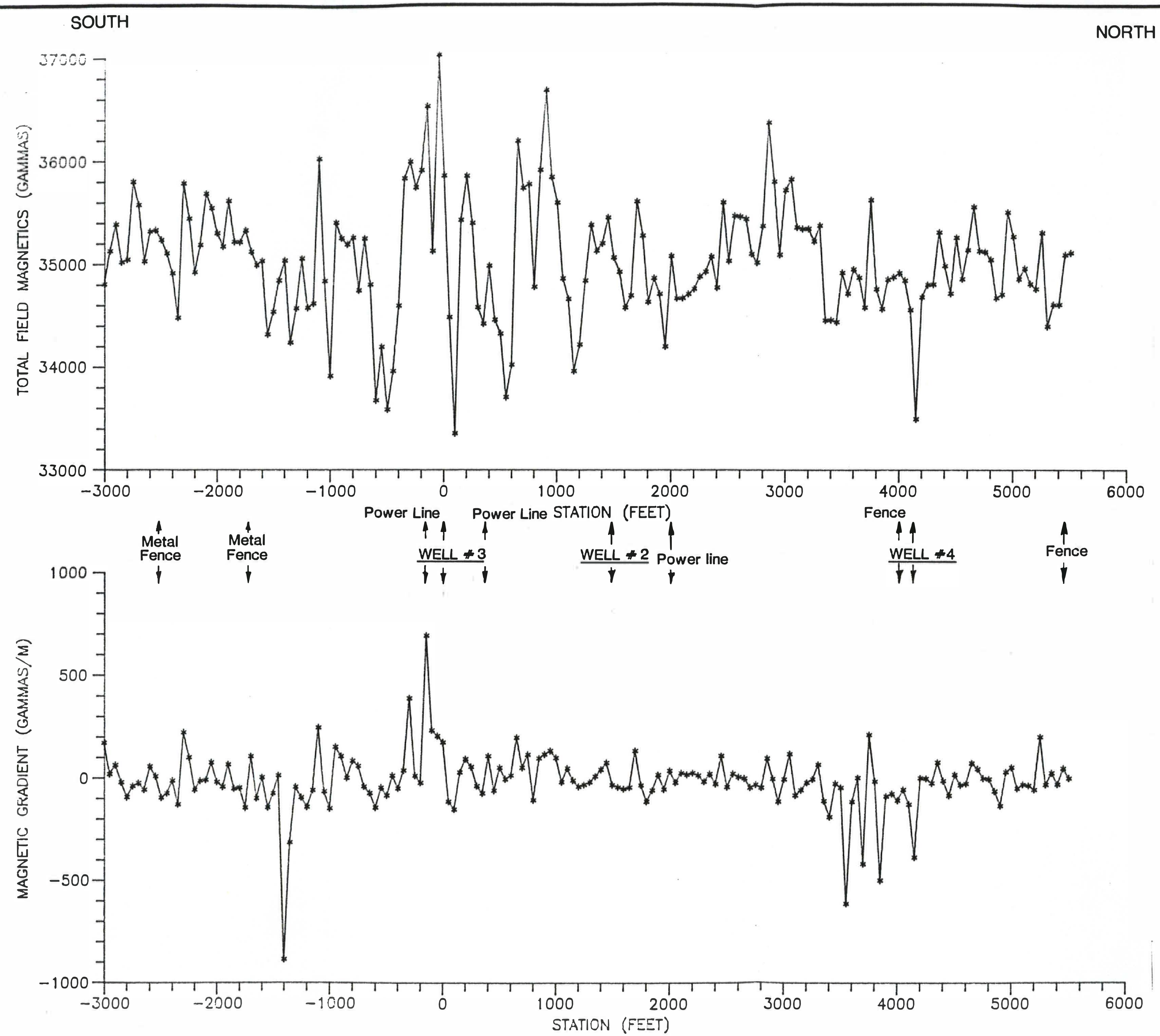
FIGURE 5-18



BISHOP ESTATES		ISLAND OF HAWAII
CRES BLACKHAWK GEOSCIENCES DIVISION		KEAUHOU NORTH KONA
Data Set: L2G3	Date: AUG-93	
Scale: 1: 14400	Profile: 200	Vertical Exaggeration: 0.41 : 1

PROJECT NO. 9038

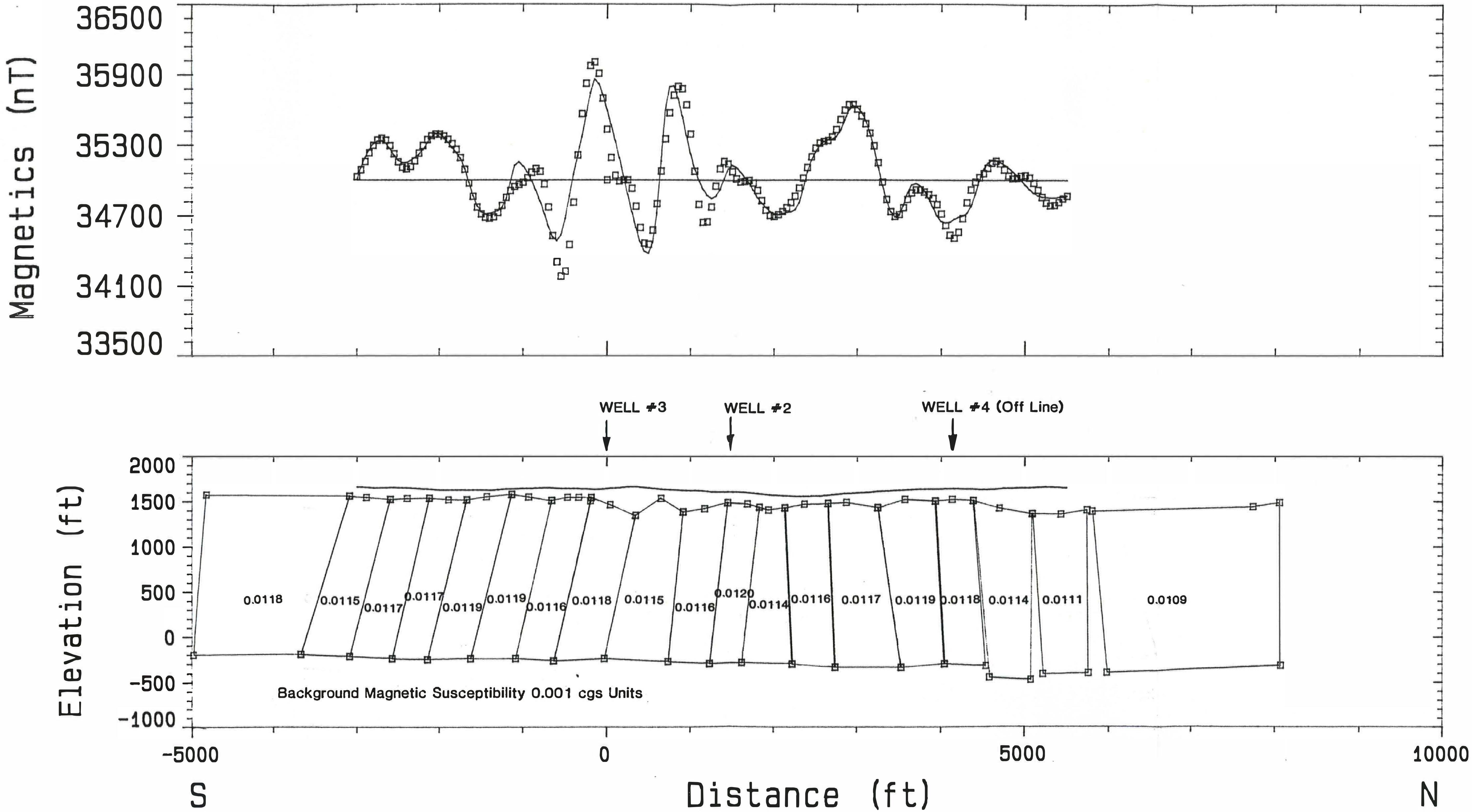
FIGURE 5-19



CEES BLACKHAWK GEOSCIENCES DIVISION

UNFILTERED MAGNETIC DATA
LINE 1
KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

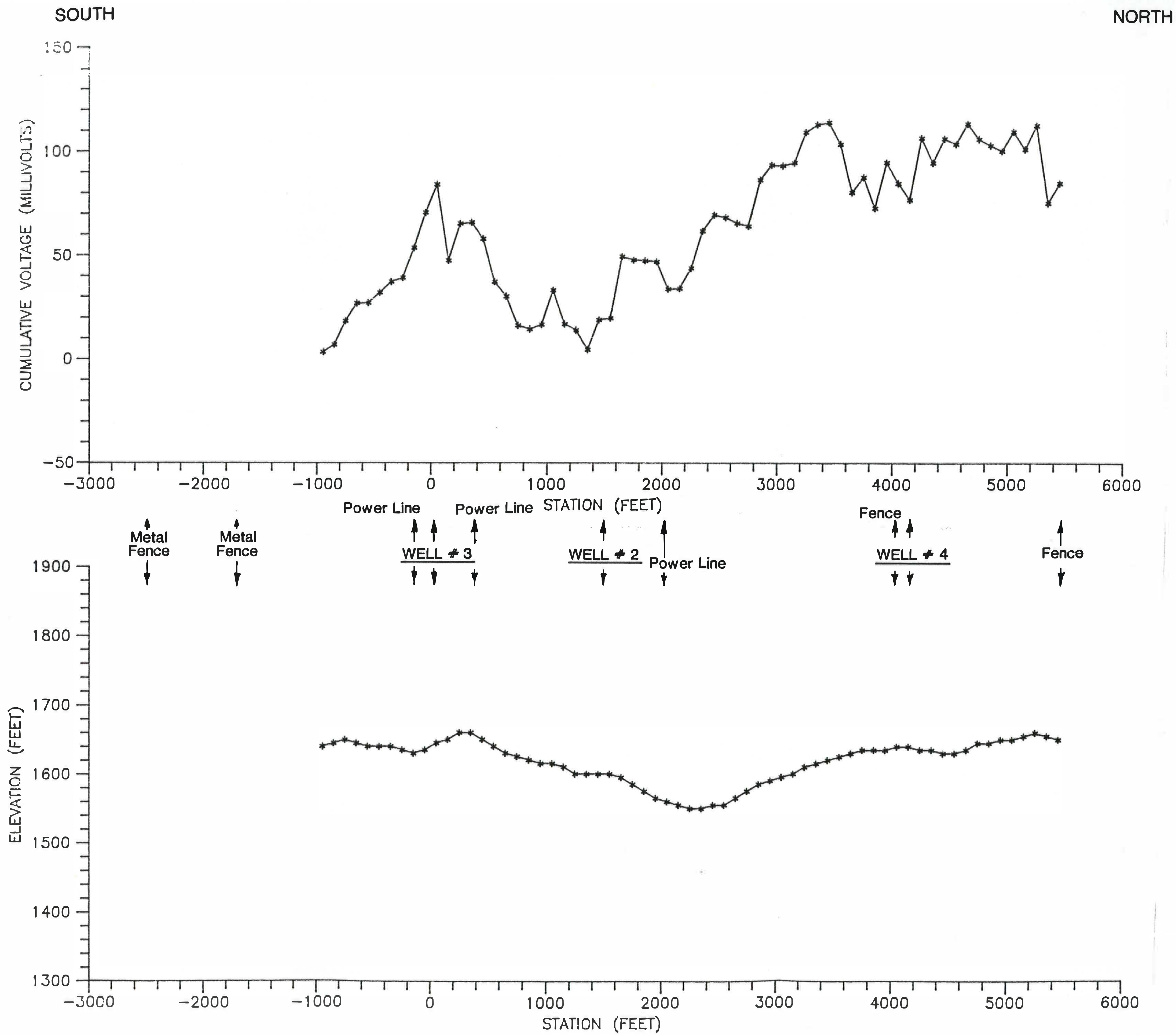
PROJECT NO. 9038 FIGURE 5-20



Inducing field : 35000. nt	BISHOP ESTATES	ISLAND OF HAWAII
Inc: 35.00 deg Dec: 11.00 deg	CEES BLACKHAWK GEOSCIENCES DIVISION	KEAUHOU NORTH KONA
Strike Direction : ****** deg		
Profile Direction : -15.00 deg	Data Set: MAG1VP — Date: AUG-93	
All Directions are Clockwise from true north	Scale: 1: 14400 — Profile: 100	Vertical Exaggeration: 1.08 : 1

PROJECT NO. 9038

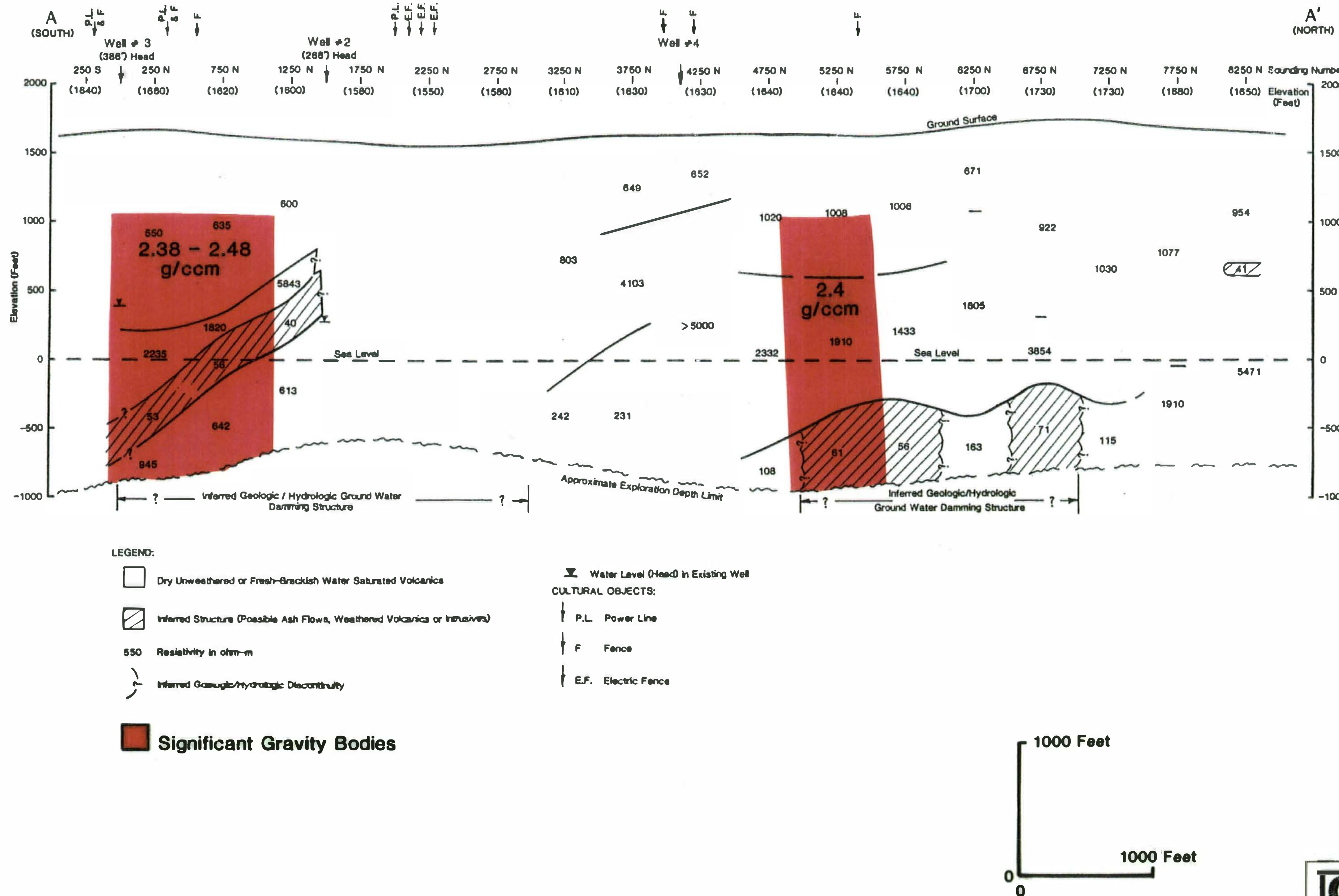
FIGURE 5-21



CEES BLACKHAWK GEOSCIENCES DIVISION

UNFILTERED SELF-POTENTIAL DATA
LINE 1
KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038 FIGURE 5-22

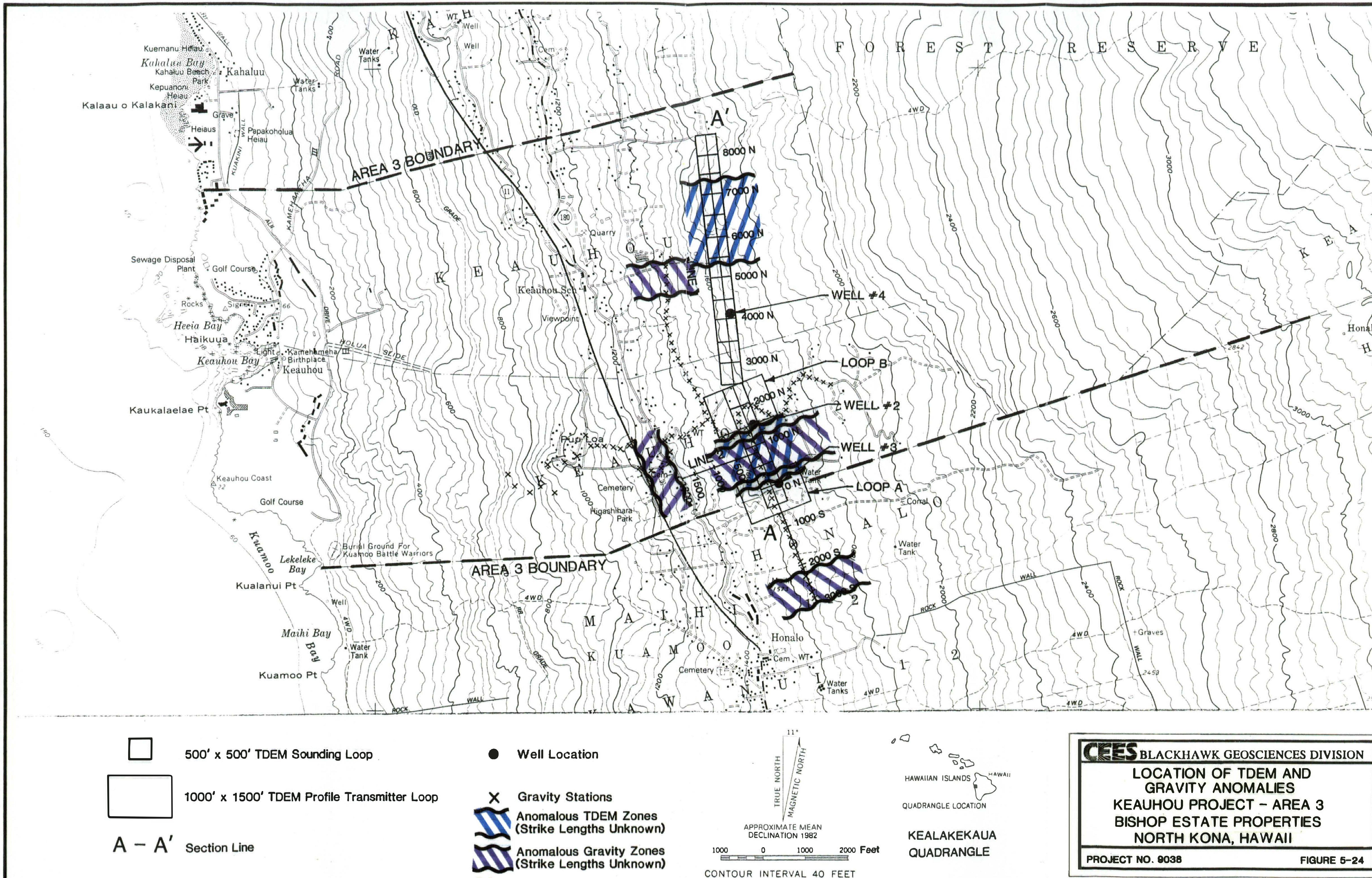


CEES BLACKHAWK GEOSCIENCES DIVISION

COMBINED INTERPRETATION SECTION
GRAVITY AND TDEM SOUNDINGS
LINE 1
KEAUHOU PROJECT - AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038

FIGURE 5-23



CEES BLACKHAWK GEOSCIENCES DIVISION

LOCATION OF TDEM AND GRAVITY ANOMALIES
KEAUHOU PROJECT – AREA 3
BISHOP ESTATE PROPERTIES
NORTH KONA, HAWAII

PROJECT NO. 9038

FIGURE 5-24

6.0 CONCLUSIONS

6.1 GENERAL

The most significant results of these investigations are:

1) That subsurface structures that cause ground water damming can be detected by both TDEM soundings and gravity surveys. This is significant for two reasons:

   i) observations of structures from geophysical measurements exploiting two different physical properties (electrical resistivity and density) gives more credence to the interpretation; and

   ii) while TDEM soundings cannot be effectively employed in built-up areas, gravity surveys can; therefore, gravity surveys can take over where TDEM soundings fail.

2) Detection by geophysical surveys of ground water damming structures perpendicular to the main ring structure parallel to the coast. This will allow delineating high-level ground water compartments, so that a better evaluation of their withdrawal potential can be made.

6.2 KAUPULEHU AREA

The interpretation of the TDEM surveys at the Kaupulehu Area (Fig. 5-6) show that this area is expected to have an extremely complicated ground water regime. Much of the area surveyed is interpreted to be influenced by structures (dikes, rift zones, etc.), and ground water yield and quality in such areas will be highly variable. In the area surveyed, basal water resources are interpreted near soundings A and B and high-level water has the potential to exist near sounding H2. The objective of the survey at Kaupulehu was to determine if the potential for high-level ground water exists above Highway 190, and this objective has been accomplished. To determine the extent of the area of potential high-level ground water, more TDEM soundings would be recommended.

6.3 PUAA AREA

One TDEM sounding was accomplished at the Puaa area (ref. Figs. 5-7 and 5-8). The interpretation of the data suggests that this sounding was located on top of, or in the close vicinity of, a ground water damming structure. Previous TDEM surveys (both north and south of Puaa) had detected this structure, and it was reported that high-level ground water was encountered in a well above Highway

190 only a short distance south of this site. This information suggests that high-level water will also be probable at locations uphill from the sounding at Puaa.

An additional sounding located uphill from PUAA1 would be recommended to confirm this prior to any exploratory work.

6.4 KEAUHOU AREA

The primary objectives of the geophysical surveys at Keauhou were:

1) Test several geophysical methods to map a postulated secondary ground water damming structure which has created a discontinuity in ground water levels between wells 2 and 3. Thus, most of the data were acquired on a roughly north-south transect on Line 1 between these wells.

2) Determine the overall effectiveness of the geophysical methods in a cultural environment (i.e., a populated and built-up area with homes, fences, power lines, etc.).

From interpretations of the TDEM sounding data, a significant change in the geoelectric section is inferred between wells 2 and 3, and from the gravity data an anomalous structure is inferred at the same location. This verification of the presence of an anomalous structure with two methods measuring different physical properties gives substantial credibility to the interpretation. The orientation of the structure is believed to be best defined with the TDEM soundings and consists of a dipping (about 20^{o} to 40^{o} to the south) combined resistive-conductive layer (Fig. 5-23).

Another potential area for ground water damming structures exists between stations 4750N and 5500N. In this vicinity the TDEM data suggests a structure below sea level, and the gravity data suggest a dense body which extends to within about 600 ft of the surface. Although both results are not the same (but similar) as that between wells 2 and 3, it also must be considered an area of likely ground water damming structures.

Gravity and TDEM sounding data were taken on separate lines (about 1,000 ft apart) in the vicinity of 4750N to 5500N. Extrapolation of the results of the two data sets over such a large distance causes some uncertainty in interpretation. The gravity data was not affected by culture in the survey area. The TDEM soundings were highly affected at four stations (250S, 1750N, 2250N and 2750N) in the vicinity of fences and power lines.

Magnetics data in the Keauhou area were highly influenced (deteriorated) by cultural noise. Modeling of the filtered data does not reveal the presence of any significant magnetic bodies in the vicinity of the two wells.

Although the TDEM sounding method did detect lateral changes in the geoelectric section on line, TDEM profiling data did not. The geoelectric section derived from TDEM soundings show resistivity changes to be small, and to occur too deep to be detectable with the profiling method.

The S.P. data provided only qualitative results. These results suggest that there may be little ground water movement between wells #2 and #3, and that ground water levels (or flow) may increase from well 2 towards well 4.

Gravity data were also acquired on an east-west profile (Line 2) in the Keauhou area. This data is noisy compared to Line 1 data, however the source of the noise was not ascertained. Several isolated, dense bodies were modeled on this profile. Because there is no other information (e.g., borehole, TDEM, etc.) along this line, the significance of the gravity anomalies is not known. The gravity anomalies on Line 2 near 0 and 1200E may be caused by the same gravity body detected on Line 1 between Station 0 and 1000N. The gravity body located near 2300W may be caused by intrusives which divide the basal and high-level ground water occurrences in the North Kona area. Additional data would be needed to confirm this interpretation. These data (and the data on Line 1) show that host rock (background or bulk) densities of the volcanic rocks do not change significantly along either profile.

7.0 RECOMMENDATIONS

The significant interpretations about ground water damming structures made at Keauhou are based on one north-south line of geophysical data. To make sweeping interpretations on one line of data requires making certain assumptions, such as assuming structures to strike perpendicular to the survey line and to have large extent perpendicular to the survey line. These assumptions can be tested and modified by additional lines.

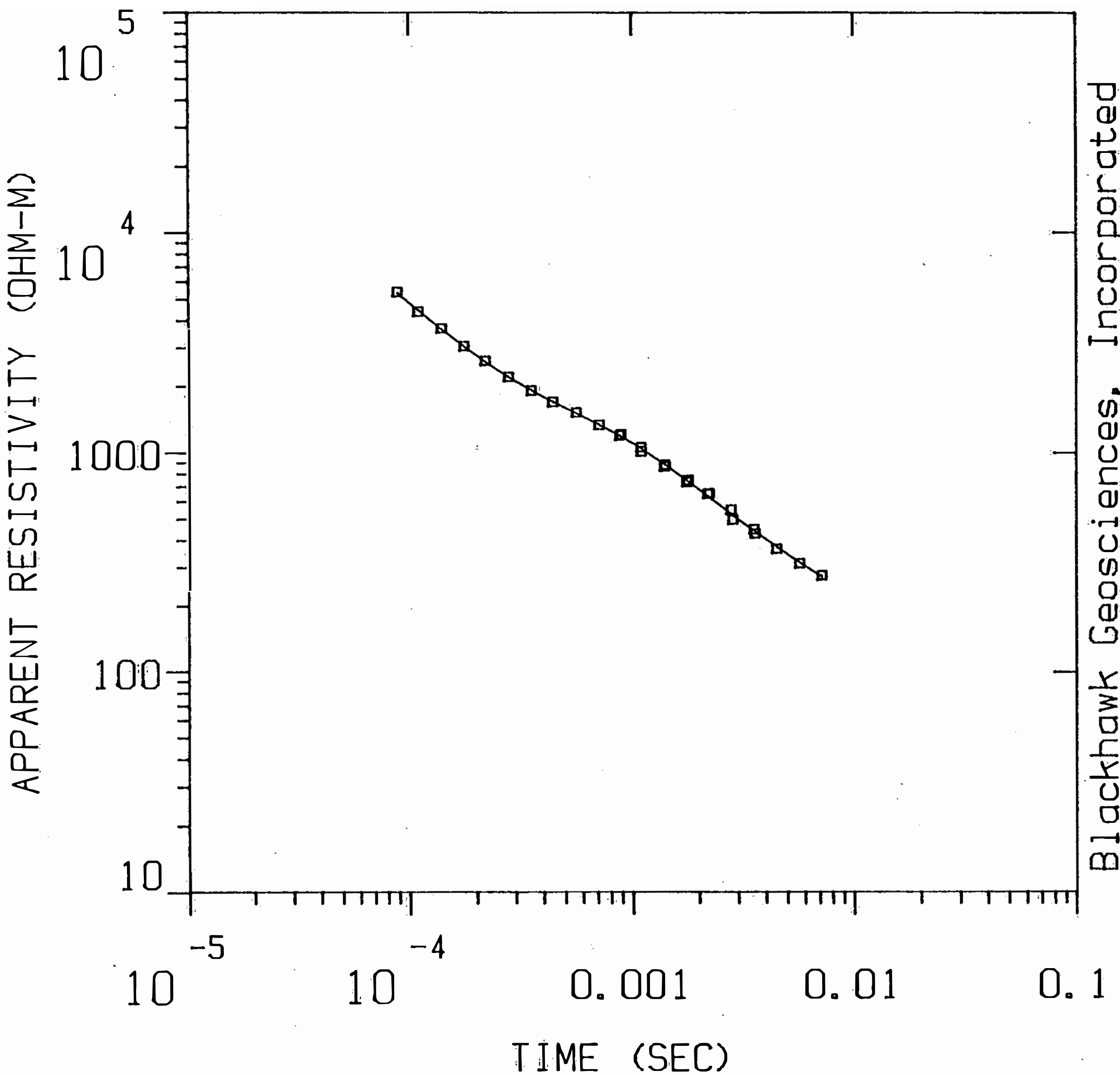
In the Keauhou area, it was shown that both gravity and TDEM soundings detected anomalous structures between wells #2 and #3 (and likely in the vicinity of 4750N and 5500N). The separate interpretation of TDEM sounding data and gravity data yielded structures at the same locations, but of different depth, width and orientation. Additional work, consisting of extensive computer modeling, may yield one integrated interpretation consistent with both data sets.

The ultimate objective of the geophysical surveys is to directly correlate it to ground water yield and water quality. With additional information from well #4, attempts can be made to establish a correlation between water levels measured in wells and geophysical data. Such correlations can be used to optimally locate other wells along line 1, and may be extrapolated to other areas.

Although the TDEM soundings at Kaupulehu indicate the potential for high-level water above Highway #190, the extent of this zone is not known. Additional TDEM soundings are recommended to further define the limits of potential high-level ground water.

At PUAA, the single TDEM sounding, and information from wells and previous TDEM soundings taken nearby, infer high-level water will exist at locations above the sounding. Additional TDEM soundings located upslope from PUAA1 would help confirm this hypothesis.

HUAL1



MODEL:

2081. OHM-M — 409. M

360. OHM-M — 436. M

53.0 OHM-M

% ERROR: 3.05
CALIBRATION: 1
OFFSET: 228. M
RAMP: 220.0

HUAL1

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		707.1	2320.0		
2081.13	408.5	298.6	979.7	0.2	0.2
359.72	436.4	-137.8	-452.0	1.2	1.4
52.97					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.38E+03	5.33E+03	0.931	
2	1.10E-04	4.38E+03	4.47E+03	-1.909	
3	1.40E-04	3.68E+03	3.66E+03	0.400	
4	1.77E-04	3.04E+03	3.04E+03	0.127	
5	2.20E-04	2.61E+03	2.59E+03	0.805	
6	2.80E-04	2.20E+03	2.20E+03	-0.021	
7	3.55E-04	1.91E+03	1.91E+03	-0.148	
8	4.43E-04	1.70E+03	1.70E+03	-0.266	
9	5.64E-04	1.52E+03	1.51E+03	0.820	
10	7.13E-04	1.34E+03	1.34E+03	-0.138	
11	8.81E-04	1.20E+03	1.20E+03	0.135	
12	8.90E-04	1.21E+03	1.19E+03	1.639	
13	1.10E-03	1.06E+03	1.05E+03	0.923	
14	1.10E-03	1.01E+03	1.04E+03	-3.156	
15	1.40E-03	8.64E+02	8.86E+02	-2.485	
16	1.41E-03	8.80E+02	8.81E+02	-0.143	
17	1.77E-03	7.33E+02	7.46E+02	-1.745	
18	1.80E-03	7.50E+02	7.39E+02	1.549	
19	2.20E-03	6.50E+02	6.33E+02	2.647	
20	2.22E-03	6.52E+02	6.28E+02	3.827	
21	2.80E-03	5.50E+02	5.27E+02	4.369	
22	2.85E-03	4.96E+02	5.20E+02	-4.721	
23	3.55E-03	4.48E+02	4.42E+02	1.409	
24	3.60E-03	4.28E+02	4.37E+02	-2.038	
25	4.49E-03	3.65E+02	3.73E+02	-2.108	
26	5.70E-03	3.13E+02	3.16E+02	-0.938	
27	7.19E-03	2.76E+02	2.72E+02	1.434	

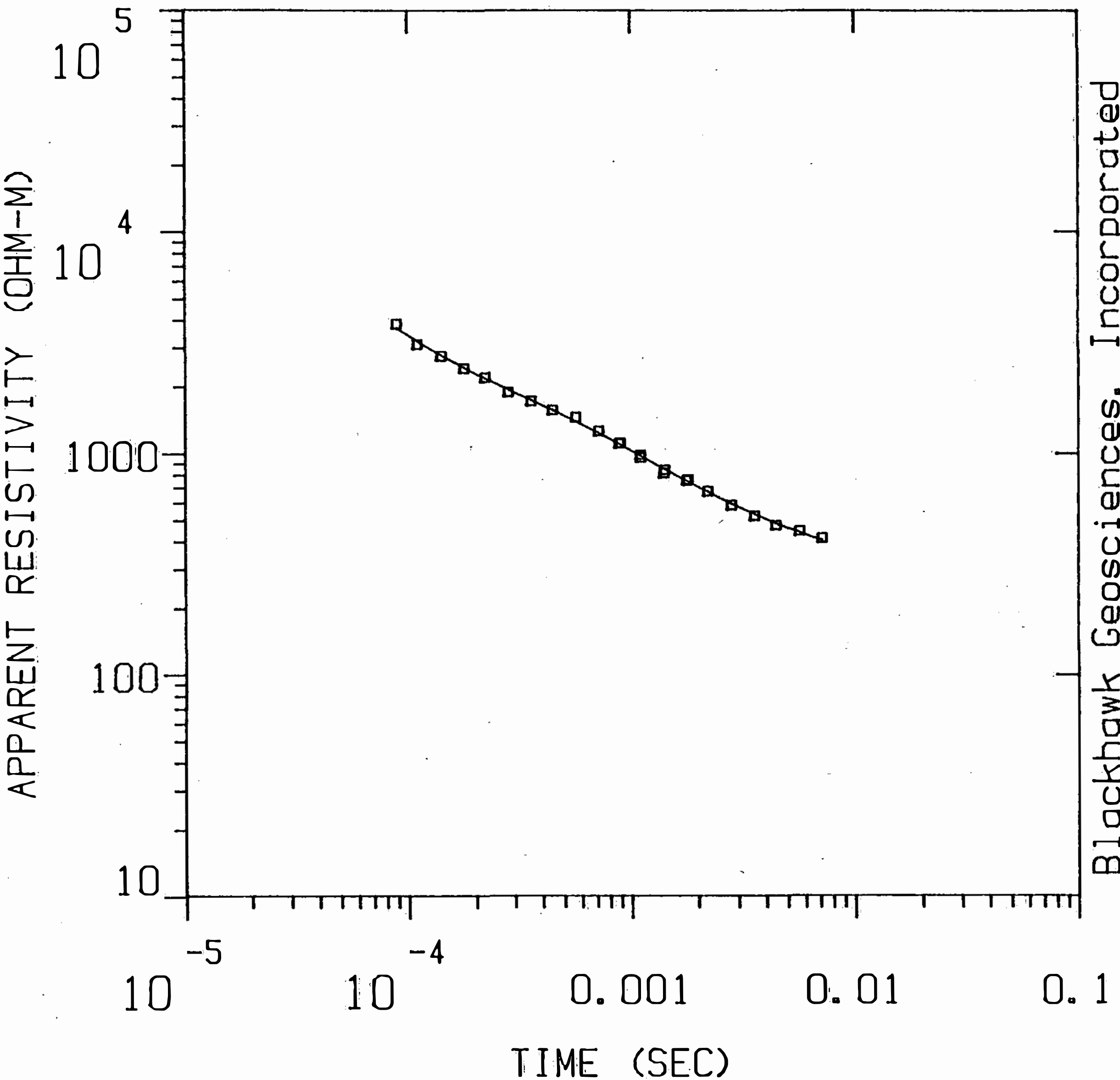
R: 228. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
CLHZ ARRAY, 27 DATA POINTS, RAMP: 220.0 MICROSEC, DATA: HUAL1
2306 100 111NZ OPR XTL L 6 10-100
Ch.21 = 0.22 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 20
RMS LOG ERROR: 1.30E-02, ANTILOG YIELDS 3.0461 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.99				
P 2	0.00	0.99			
P 3	0.00	0.00	1.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	P 3	T 1	T 2

HUAL2



MODEL:

Resistivity	Thickness
1356. OHM-M	312. M
716. OHM-M	425. M
187. OHM-M	

% ERROR: 3.34
CALIBRATION: 1
OFFSET: 229. M
RAMP: 220.0

HUAL2

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		713.2	2340.0		
1356.42	312.3	401.0	1315.5	0.2	0.2
715.75	424.7	-23.7	-77.9	0.6	0.8
187.36					

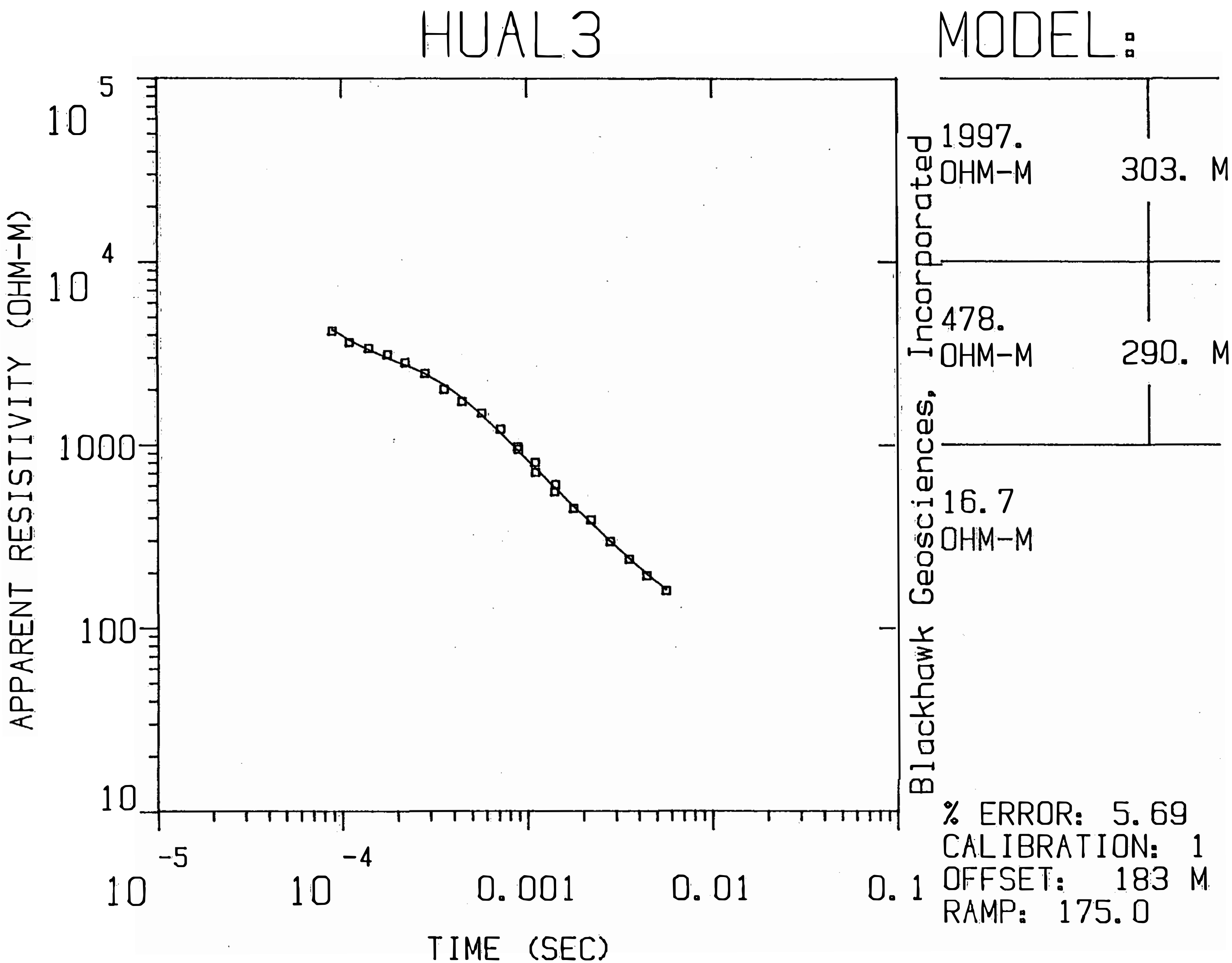
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	3.83E+03	3.67E+03	4.362	
2	1.10E-04	3.09E+03	3.20E+03	-3.406	
3	1.40E-04	2.74E+03	2.76E+03	-0.869	
4	1.77E-04	2.41E+03	2.42E+03	-0.606	
5	2.20E-04	2.19E+03	2.17E+03	0.999	
6	2.80E-04	1.88E+03	1.93E+03	-2.622	
7	3.55E-04	1.71E+03	1.73E+03	-1.186	
8	4.43E-04	1.56E+03	1.56E+03	0.021	
9	5.64E-04	1.45E+03	1.39E+03	4.383	
10	7.13E-04	1.25E+03	1.23E+03	1.918	
11	8.81E-04	1.11E+03	1.10E+03	0.756	
12	8.90E-04	1.11E+03	1.09E+03	1.288	
13	1.10E-03	9.80E+02	9.73E+02	0.710	
14	1.10E-03	9.57E+02	9.71E+02	-1.493	
15	1.40E-03	8.12E+02	8.50E+02	-4.493	
16	1.41E-03	8.39E+02	8.46E+02	-0.826	
17	1.77E-03	7.52E+02	7.48E+02	0.436	
18	1.80E-03	7.59E+02	7.43E+02	2.134	
19	2.20E-03	6.72E+02	6.68E+02	0.578	
20	2.80E-03	5.82E+02	5.93E+02	-1.855	
21	3.55E-03	5.22E+02	5.32E+02	-1.840	
22	4.43E-03	4.73E+02	4.83E+02	-2.106	
23	5.64E-03	4.46E+02	4.39E+02	1.520	
24	7.13E-03	4.14E+02	4.04E+02	2.639	

R: 229. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
CLHZ ARRAY, 24 DATA POINTS, RAMP: 220.0 MICROSEC, DATA: HUAL2
2406 100N 222NZ OPR L 6 10-100
Ch.21 = 0.22 Ch.22 = 0.89 Ch.23 = 13.2 Ch.24 =
RMS LOG ERROR: 1.43E-02, ANTILOG YIELDS 3.3405 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.78				
P 2	0.11	0.44			
P 3	0.00	-0.10	0.61		
T 1	0.17	0.30	0.05	0.42	
T 2	-0.16	0.02	0.16	0.32	0.57
	P 1	P 2	P 3	T 1	T 2


HUAL3
MODEL:
1997.
OHM-M
303. M
478.
OHM-M
290. M
16.7
OHM-M
Blackhawk Geosciences, Incorporated
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
% ERROR: 5.69
CALIBRATION: 1
OFFSET: 183 M
RAMP: 175.0

HUAL3

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		574.5	1885.0		
1996.71	302.7	271.9	891.9	0.2	0.2
478.28	289.7	-17.9	-58.7	0.6	0.8
16.71					

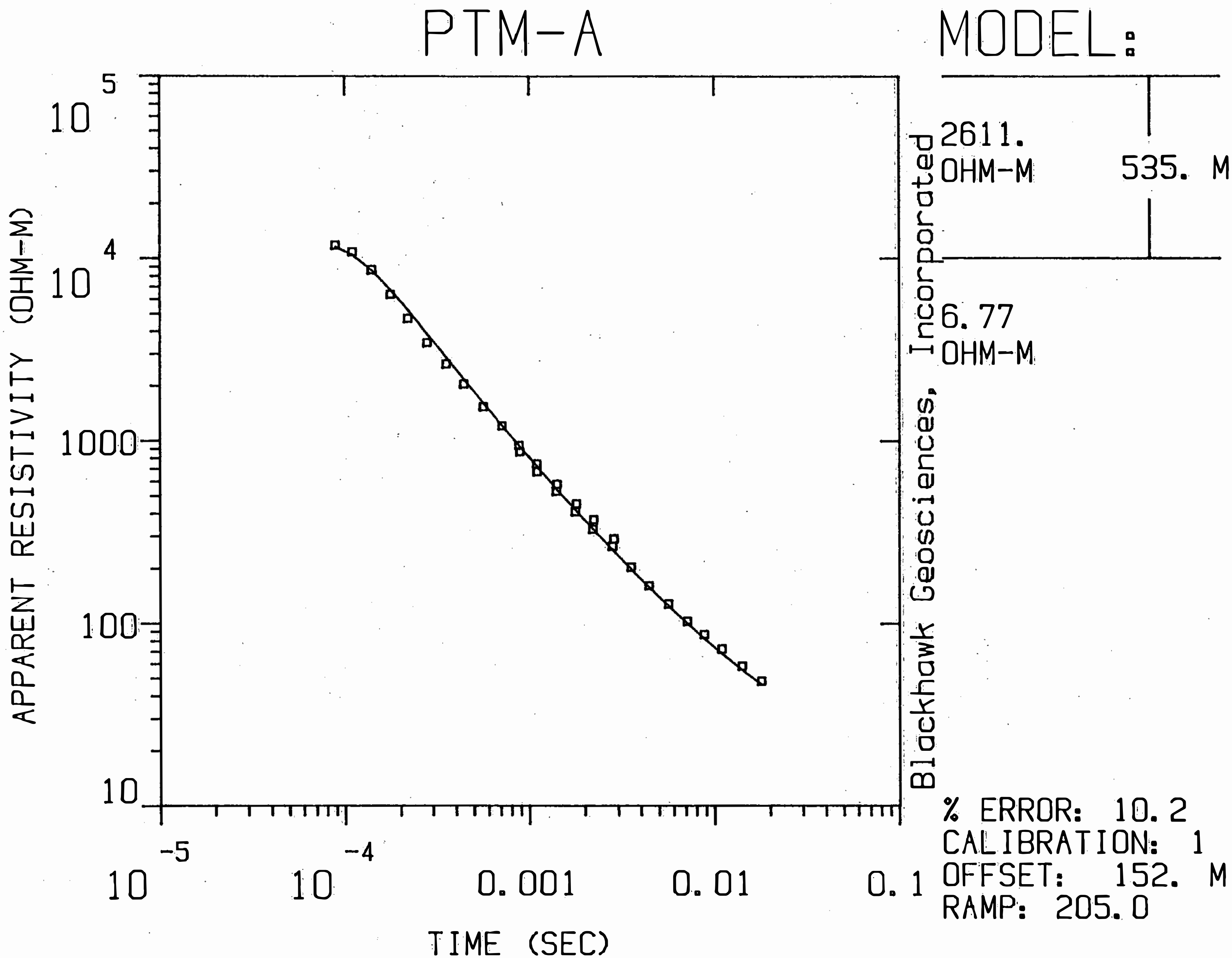
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	4.18E+03	4.26E+03	-1.846	
2	1.10E-04	3.62E+03	3.74E+03	-3.195	
3	1.40E-04	3.35E+03	3.30E+03	1.592	
4	1.77E-04	3.10E+03	2.98E+03	4.227	
5	2.20E-04	2.80E+03	2.72E+03	3.029	
6	2.80E-04	2.44E+03	2.43E+03	0.235	
7	3.55E-04	2.00E+03	2.12E+03	-5.789	
8	4.43E-04	1.71E+03	1.80E+03	-4.752	
9	5.64E-04	1.49E+03	1.46E+03	1.978	
10	7.13E-04	1.21E+03	1.16E+03	4.493	
11	8.81E-04	9.72E+02	9.38E+02	3.615	
12	8.90E-04	9.43E+02	9.28E+02	1.565	
13	1.10E-03	7.99E+02	7.50E+02	6.464	
14	1.10E-03	7.05E+02	7.48E+02	-5.771	
15	1.40E-03	5.54E+02	5.85E+02	-5.330	
16	1.41E-03	6.06E+02	5.81E+02	4.393	
17	1.77E-03	4.48E+02	4.63E+02	-3.174	
18	2.20E-03	3.89E+02	3.74E+02	3.874	
19	2.80E-03	2.96E+02	2.98E+02	-0.778	
20	3.55E-03	2.37E+02	2.40E+02	-1.134	
21	4.43E-03	1.92E+02	1.98E+02	-2.570	
22	5.64E-03	1.59E+02	1.61E+02	-1.512	

R: 183. X: 0. Y: 183. DL: 366. REQ: 203. CF: 1.0000
CLHZ ARRAY, 22 DATA POINTS, RAMP: 175.0 MICROSEC, DATA: HUAL3
0607 200N 200WZ OPR L 6 10+TXL=366*366
Ch.21 = 0.175 Ch.22 = 0.89 Ch.23 = 12.2 Ch.24 =
RMS LOG ERROR: 2.40E-02, ANTILOG YIELDS 5.6853 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.26				
P 2	0.15	0.26			
P 3	0.02	-0.07	0.20		
T 1	0.19	0.24	-0.07	0.75	
T 2	-0.21	-0.22	0.04	0.23	0.72


PTM-A
MODEL:
2611.
OHM-M
535. M
6.77
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
0.001
0.01
0.1
1000
100
10
Blackhawk Geosciences, Incorporated
% ERROR: 10.2
CALIBRATION: 1
OFFSET: 152. M
RAMP: 205.0

PTM-A

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		402.3	1320.0		
2611.14	534.7	-132.4	-434.3	0.2	0.2
6.77					

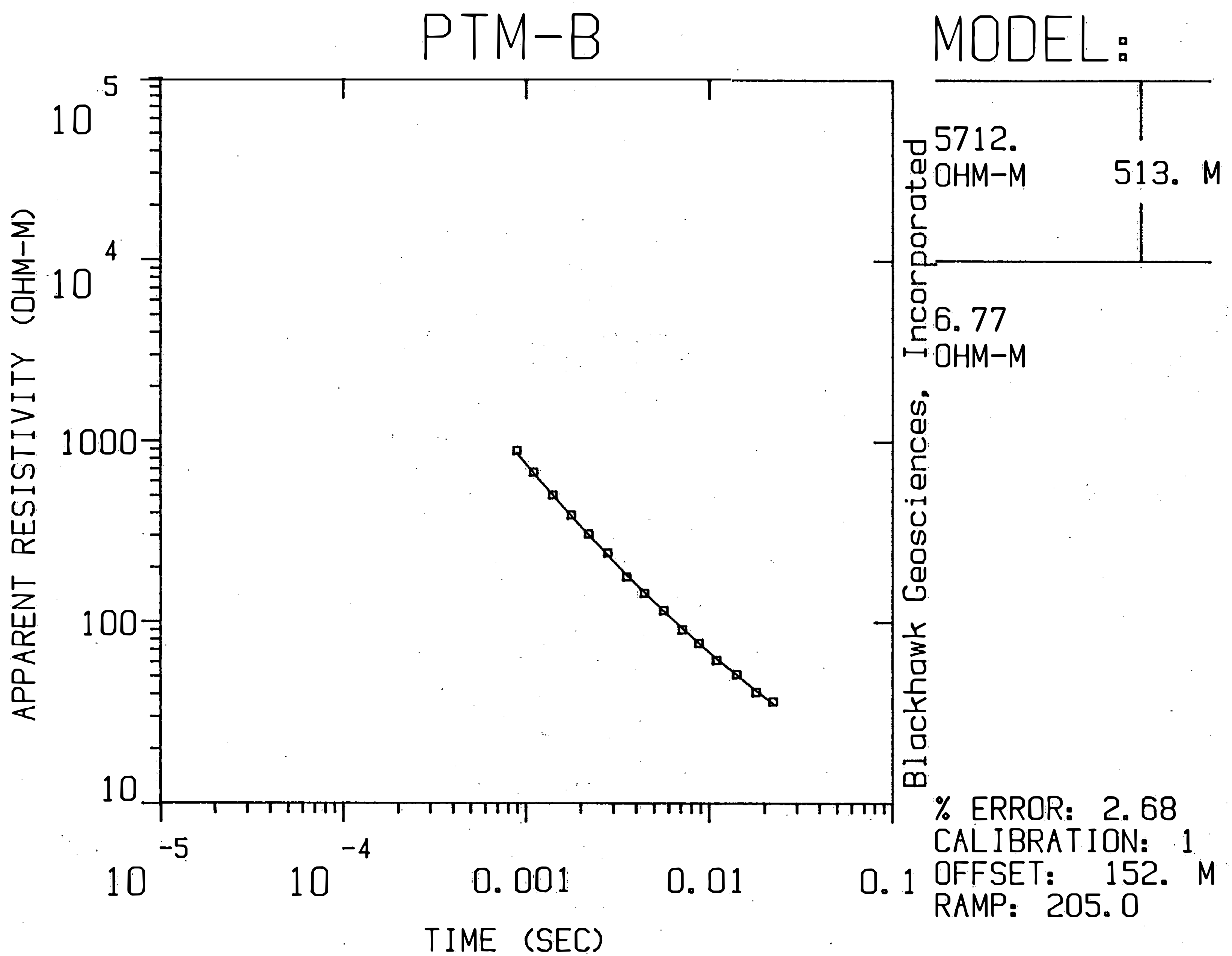
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.44E-02	1.47E-02	-2.666	
2	1.10E-04	9.60E-03	1.02E-02	-5.451	
3	1.40E-04	7.38E-03	7.40E-03	-0.325	
4	1.77E-04	6.51E-03	5.94E-03	9.605	
5	2.20E-04	5.95E-03	5.02E-03	18.569	
6	2.80E-04	5.17E-03	4.32E-03	19.447	
7	3.55E-04	4.28E-03	3.74E-03	14.488	
8	4.43E-04	3.60E-03	3.24E-03	10.979	
9	5.64E-04	3.01E-03	2.78E-03	8.299	
10	7.13E-04	2.40E-03	2.38E-03	0.807	
11	8.81E-04	2.06E-03	2.05E-03	0.477	
12	8.90E-04	2.26E-03	2.04E-03	11.119	
13	1.10E-03	1.69E-03	1.75E-03	-3.417	
14	1.10E-03	1.95E-03	1.75E-03	11.483	
15	1.40E-03	1.54E-03	1.46E-03	5.667	
16	1.41E-03	1.32E-03	1.45E-03	-9.116	
17	1.77E-03	1.26E-03	1.21E-03	4.405	
18	1.80E-03	1.04E-03	1.19E-03	-12.589	
19	2.20E-03	1.02E-03	1.01E-03	1.003	
20	2.22E-03	8.25E-04	1.00E-03	-17.468	
21	2.80E-03	7.71E-04	8.16E-04	-5.527	
22	2.85E-03	6.41E-04	8.03E-04	-20.121	
23	3.55E-03	6.30E-04	6.54E-04	-3.758	
24	4.43E-03	5.14E-04	5.29E-04	-2.805	
25	5.64E-03	3.98E-04	4.11E-04	-3.196	
26	7.13E-03	3.07E-04	3.19E-04	-3.985	
27	8.81E-03	2.32E-04	2.50E-04	-7.461	
28	1.10E-02	1.77E-04	1.92E-04	-7.927	
29	1.41E-02	1.31E-04	1.40E-04	-6.917	
30	1.80E-02	9.49E-05	1.01E-04	-6.181	

R: 152. X: 0. Y: 153. DL: 305. REQ: 170. CF: 1.0000
TDHZ ARRAY, 30 DATA POINTS, RAMP: 205.0 MICROSEC, DATA: PTM-A
0404 002N 0002 Z OPR XTL H 6 8+100
Ch.21 = 0.205 Ch.22 = 0.089 Ch.23 = 21 Ch.24 =
RMS LOG ERROR: 4.21E-02, ANTILOG YIELDS 10.1894 %
EARLY TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1



PTM-B
MODEL:
5712.
OHM-M
513. M
6.77
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 2.68
CALIBRATION: 1
OFFSET: 152. M
RAMP: 205.0

PTM-B

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		408.4	1340.0		
5712.31	513.0	-104.5	-343.0	0.1	0.1
6.77					

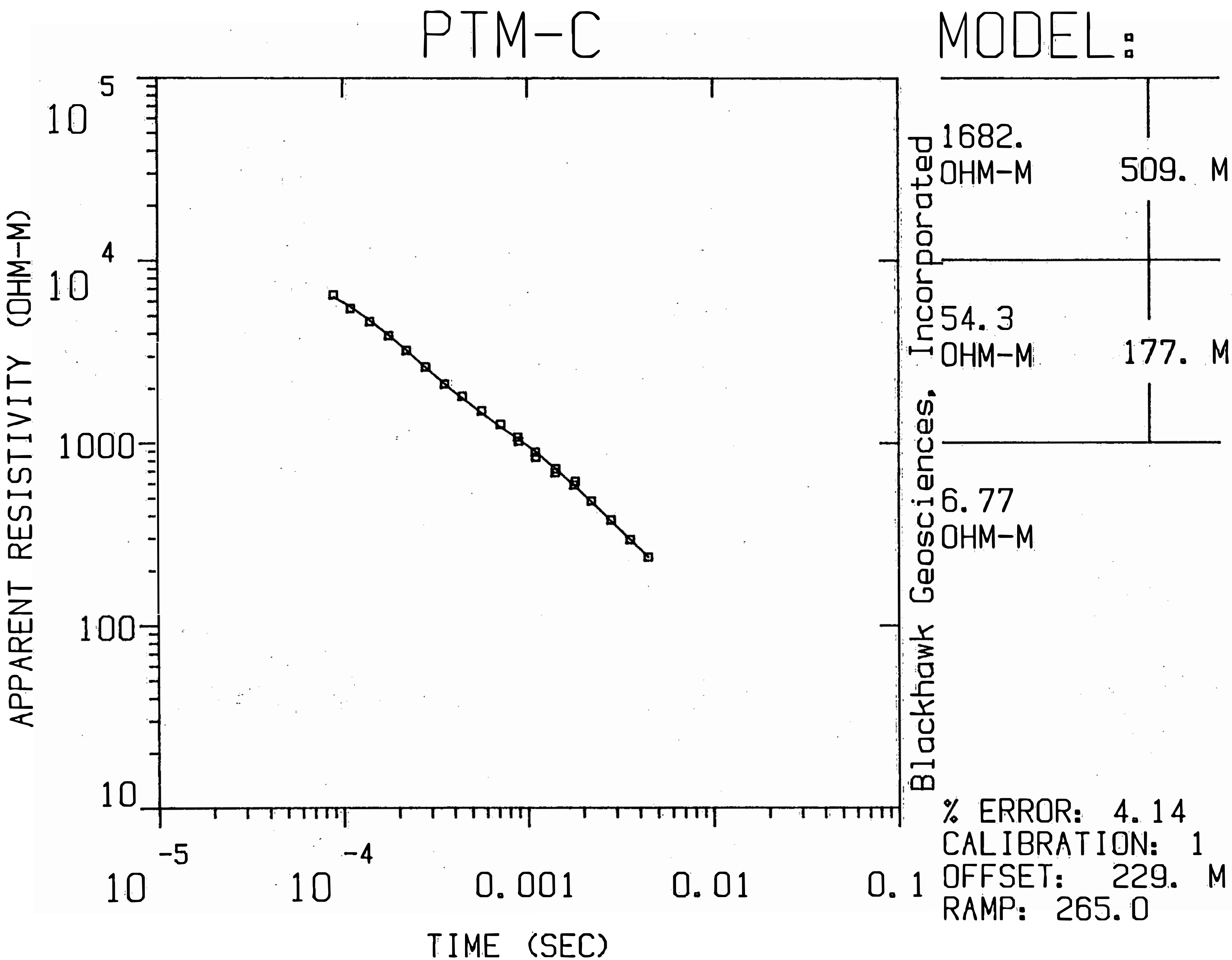
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-04	2.20E-03	2.29E-03	-3.963	
2	1.10E-03	1.95E-03	1.97E-03	-0.827	
3	1.40E-03	1.65E-03	1.64E-03	0.595	
4	1.77E-03	1.35E-03	1.37E-03	-1.122	
5	2.20E-03	1.13E-03	1.14E-03	-0.968	
6	2.80E-03	8.88E-04	9.21E-04	-3.615	
7	3.55E-03	7.73E-04	7.41E-04	4.316	
8	4.43E-03	6.06E-04	5.95E-04	1.838	
9	5.64E-03	4.63E-04	4.65E-04	-0.455	
10	7.13E-03	3.72E-04	3.61E-04	3.312	
11	8.81E-03	2.83E-04	2.83E-04	0.228	
12	1.10E-02	2.27E-04	2.19E-04	3.708	
13	1.41E-02	1.58E-04	1.59E-04	-0.640	
14	1.80E-02	1.21E-04	1.17E-04	3.369	
15	2.22E-02	8.49E-05	8.83E-05	-3.796	

R: 152. X: 0. Y: 153. DL: 305. REQ: 170. CF: 1.0000
TDHZ ARRAY, 15 DATA POINTS, RAMP: 205.0 MICROSEC, DATA: PTM-B
0404 003N 0003 Z OPR XTL L 7 10+100
Ch.21 = 0.205 Ch.22 = 0.89 Ch.23 = 20 Ch.24 = 9
RMS LOG ERROR: 1.15E-02, ANTILOG YIELDS 2.6788 %
EARLY TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.06		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1


PTM-C
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
1682. OHM-M
509. M
54.3 OHM-M
177. M
6.77 OHM-M
% ERROR: 4.14
CALIBRATION: 1
OFFSET: 229. M
RAMP: 265.0

PTM-C

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		579.1	1900.0		
1682.15	509.3	69.8	229.1	0.3	0.3
54.30	177.1	-107.3	-352.0	3.3	3.6
6.77					

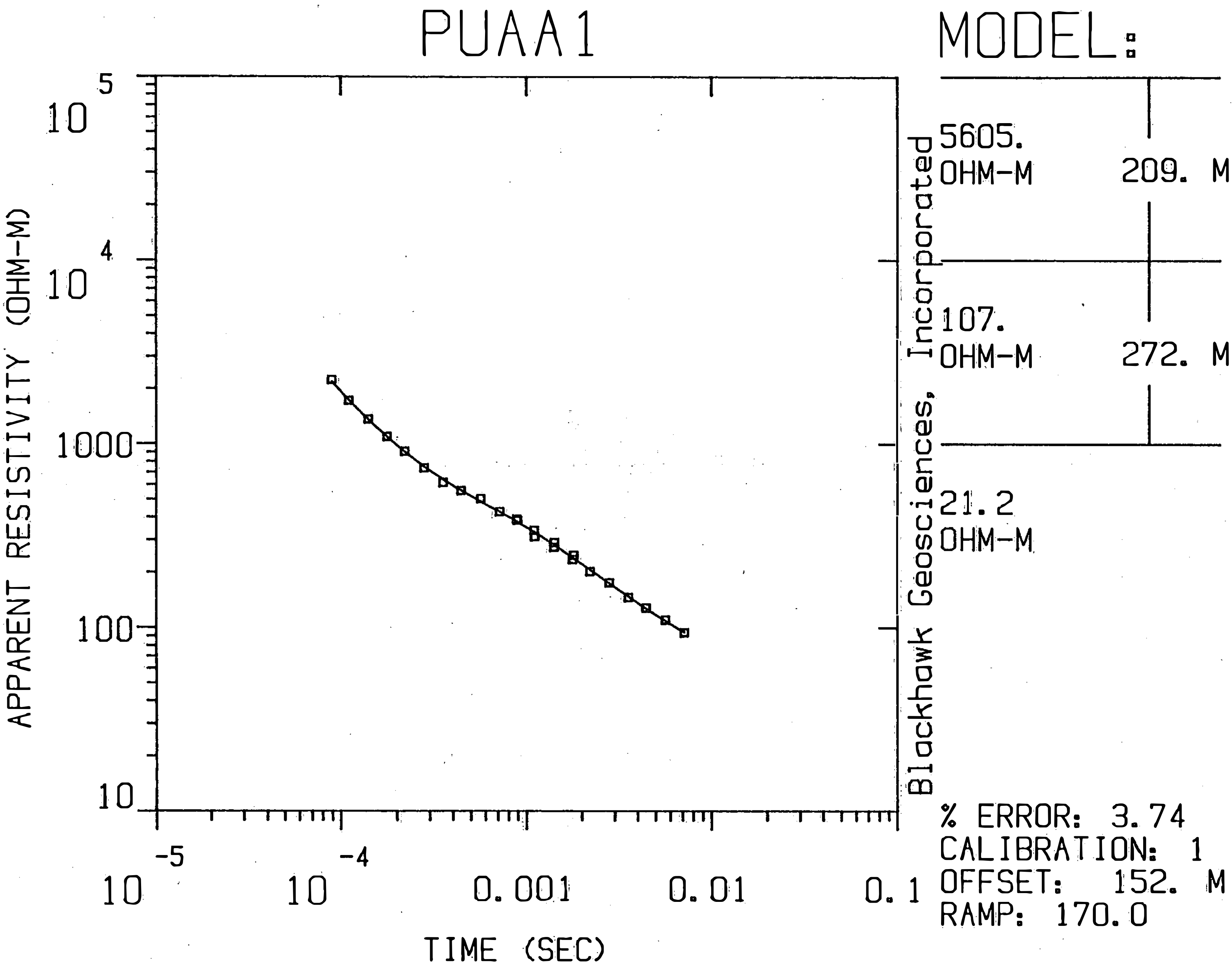
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	6.48E+03	6.31E+03	2.680	
2	1.10E-04	5.46E+03	5.58E+03	-2.162	
3	1.40E-04	4.63E+03	4.73E+03	-1.987	
4	1.77E-04	3.88E+03	3.91E+03	-0.817	
5	2.20E-04	3.23E+03	3.24E+03	-0.460	
6	2.80E-04	2.62E+03	2.61E+03	0.417	
7	3.55E-04	2.11E+03	2.11E+03	-0.211	
8	4.43E-04	1.81E+03	1.77E+03	2.293	
9	5.64E-04	1.50E+03	1.47E+03	2.447	
10	7.13E-04	1.27E+03	1.23E+03	3.200	
11	8.81E-04	1.07E+03	1.05E+03	1.944	
12	8.90E-04	1.02E+03	1.05E+03	-2.520	
13	1.10E-03	8.89E+02	8.96E+02	-0.801	
14	1.10E-03	8.34E+02	8.93E+02	-6.620	
15	1.40E-03	6.88E+02	7.25E+02	-5.157	
16	1.41E-03	7.20E+02	7.20E+02	0.063	
17	1.77E-03	5.89E+02	5.87E+02	0.370	
18	1.80E-03	6.15E+02	5.79E+02	6.194	
19	2.20E-03	4.80E+02	4.77E+02	0.732	
20	2.80E-03	3.78E+02	3.75E+02	0.778	
21	3.55E-03	2.95E+02	2.96E+02	-0.337	
22	4.43E-03	2.37E+02	2.37E+02	-0.042	

R: 229. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
TDHZ ARRAY, 22 DATA POINTS, RAMP: 265.0 MICROSEC, DATA: PTM-C
0304 001N 0001 Z OPR XTL L 6 10+100
Ch.21 = 0.265 Ch.22 = 0.89 Ch.23 = 18.5 Ch.24 =
RMS LOG ERROR: 1.76E-02, ANTILOG YIELDS 4.1430 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
F 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	F 3	T 1	T 2



PUAA1
MODEL:
5605.
OHM-M
209. M
107.
OHM-M
272. M
21.2
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 3.74
CALIBRATION: 1
OFFSET: 152. M
RAMP: 170.0

PUAA1

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		487.7	1600.0		
5605.01	209.3	278.3	913.2	0.0	0.0
106.80	271.5	6.8	22.3	2.5	2.6
21.18					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.23E+03	2.18E+03	2.236	
2	1.10E-04	1.72E+03	1.73E+03	-1.087	
3	1.40E-04	1.36E+03	1.36E+03	0.127	
4	1.77E-04	1.09E+03	1.09E+03	0.316	
5	2.20E-04	9.05E+02	9.02E+02	0.293	
6	2.80E-04	7.35E+02	7.49E+02	-1.924	
7	3.55E-04	6.13E+02	6.37E+02	-3.663	
8	4.43E-04	5.54E+02	5.56E+02	-0.351	
9	5.64E-04	5.02E+02	4.85E+02	3.538	
10	7.13E-04	4.26E+02	4.26E+02	0.015	
11	8.81E-04	3.88E+02	3.78E+02	2.663	
12	8.90E-04	3.84E+02	3.76E+02	2.227	
13	1.10E-03	3.37E+02	3.31E+02	1.956	
14	1.10E-03	3.11E+02	3.30E+02	-5.794	
15	1.40E-03	2.72E+02	2.82E+02	-3.544	
16	1.41E-03	2.89E+02	2.80E+02	3.190	
17	1.77E-03	2.33E+02	2.40E+02	-2.690	
18	1.80E-03	2.47E+02	2.37E+02	4.041	
19	2.20E-03	2.00E+02	2.05E+02	-2.380	
20	2.80E-03	1.74E+02	1.73E+02	0.849	
21	3.55E-03	1.45E+02	1.47E+02	-1.122	
22	4.43E-03	1.28E+02	1.26E+02	0.970	
23	5.64E-03	1.10E+02	1.08E+02	1.248	
24	7.13E-03	9.35E+01	9.40E+01	-0.512	

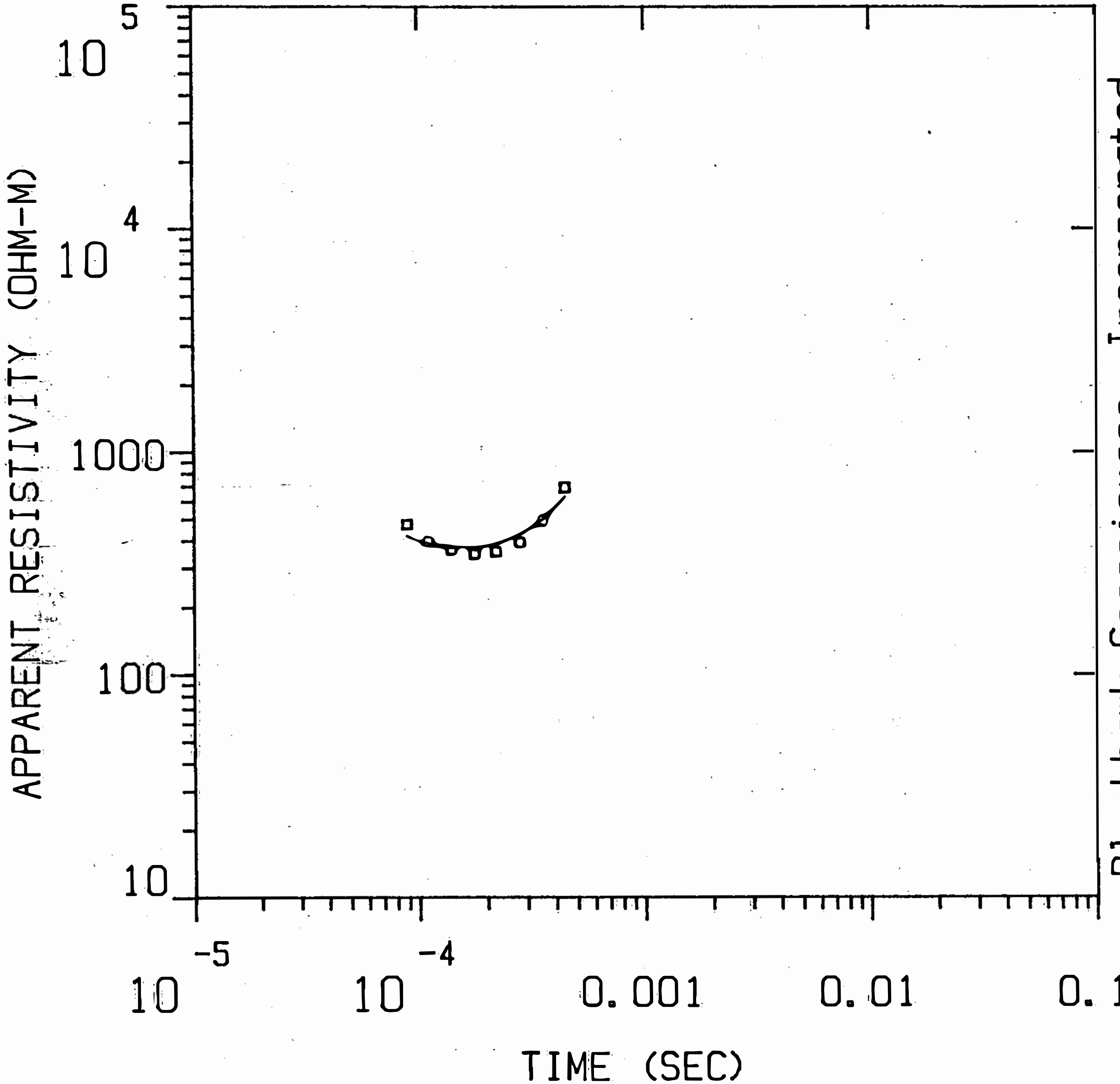
R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 24 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: PUAA1
2406 200N 333NZ OPR L 6 10-100
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 14 Ch.24 = 92
RMS LOG ERROR: 1.59E-02, ANTILOG YIELDS 3.7408 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.02				
P 2	-0.02	1.00			
P 3	0.00	0.00	1.00		
T 1	0.04	0.00	0.00	1.00	
T 2	-0.03	0.00	0.00	0.00	1.00
	P 1	P 2	P 3	T 1	T 2

L1S250S



Blackhawk Geosciences, Incorporated

MODEL:

197. OHM-M	249. M
88915. OHM-M	53.6 M
0.000 OHM-M	

% ERROR: 11.6
CALIBRATION: 1
OFFSET: 76 M
RAMP: 115.0

L1S250S

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		499.9	1640.0		
196.56	248.7	251.2	824.0	1.3	1.3
88915.17	53.6	197.5	648.1	0.0	1.3
0.00					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	4.73E+02	4.15E+02	13.829	
2	1.10E-04	3.96E+02	3.88E+02	2.197	
3	1.40E-04	3.64E+02	3.70E+02	-1.853	
4	1.77E-04	3.48E+02	3.69E+02	-5.847	
5	2.20E-04	3.57E+02	3.84E+02	-7.123	
6	2.80E-04	3.94E+02	4.25E+02	-7.262	
7	3.55E-04	4.95E+02	5.03E+02	-1.504	
8	4.43E-04	6.98E+02	6.31E+02	10.712	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 8 DATA POINTS, RAMP: 115.0 MICROSEC, DATA: L1S250S
2806 100N 25SZ OPR H 5 10-100
Ch.21 = 0.115 Ch.22 = 0.089 Ch.23 = 18 Ch.24 =
RMS LOG ERROR: 4.77E-02, ANTILOG YIELDS 11.6188 %
LATE TIME PARAMETERS

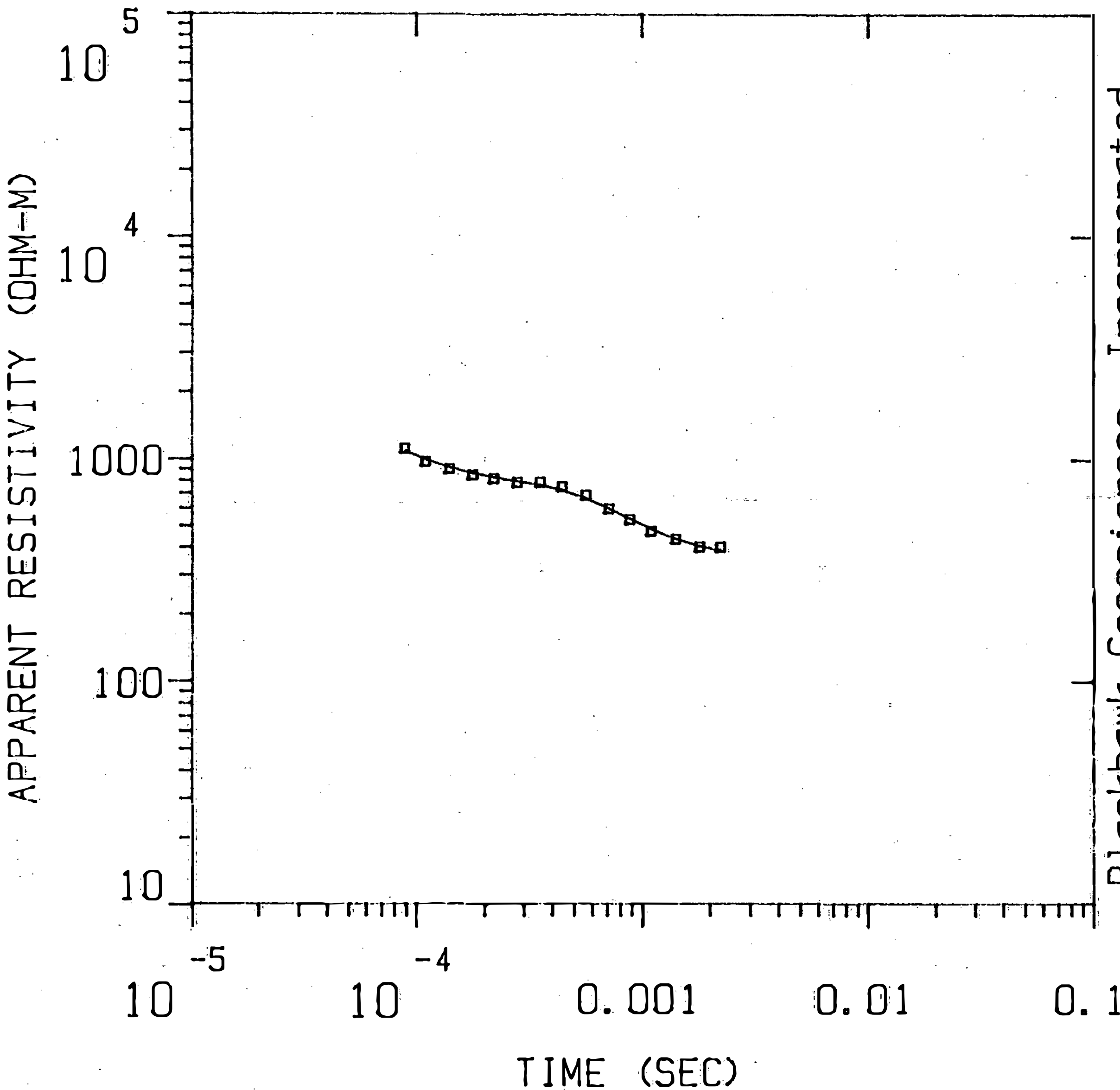
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 115.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.99				
P 2	0.00	0.00			
P 3	0.00	0.00	0.00		
T 1	-0.01	0.00	0.00	0.95	
T 2	-0.01	0.00	0.00	0.19	0.04
	P 1	P 2	P 3	T 1	T 2

L1S250N



Blackhawk Geosciences, Incorporated

MODEL:

550. OHM-M 438. M

2235. OHM-M 146. M

53.0 OHM-M 88.8 M

945. OHM-M

% ERROR: 3.44
CALIBRATION: 1
OFFSET: 76 M
RAMP: 115.0

L1S250N

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		506.0	1660.0		
550.19	438.5	67.5	221.4	0.8	0.8
2234.88	145.9	-78.4	-257.4	0.1	0.9
52.99	88.8	-167.2	-548.6	1.7	2.5
945.06					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.12E+03	1.09E+03	2.578	
2	1.10E-04	9.73E+02	9.98E+02	-2.542	
3	1.40E-04	9.01E+02	9.18E+02	-1.818	
4	1.77E-04	8.44E+02	8.61E+02	-2.013	
5	2.20E-04	8.11E+02	8.25E+02	-1.623	
6	2.80E-04	7.85E+02	7.94E+02	-1.168	
7	3.55E-04	7.87E+02	7.64E+02	3.052	
8	4.43E-04	7.53E+02	7.26E+02	3.735	
9	5.64E-04	6.87E+02	6.67E+02	2.922	
10	7.13E-04	5.97E+02	6.00E+02	-0.587	
11	8.81E-04	5.34E+02	5.40E+02	-1.160	
12	1.10E-03	4.74E+02	4.86E+02	-2.552	
13	1.41E-03	4.36E+02	4.38E+02	-0.336	
14	1.80E-03	4.03E+02	4.06E+02	-0.727	
15	2.22E-03	4.02E+02	3.88E+02	3.514	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 115.0 MICROSEC, DATA: L1S250N
3006 100N 2500NZ OPR H 6 8 +100
Ch.21 = 0.115 Ch.22 = 0.089 Ch.23 = 17.5 Ch.24
RMS LOG ERROR: 1.47E-02, ANTILOG YIELDS 3.4434 %
LATE TIME PARAMETERS

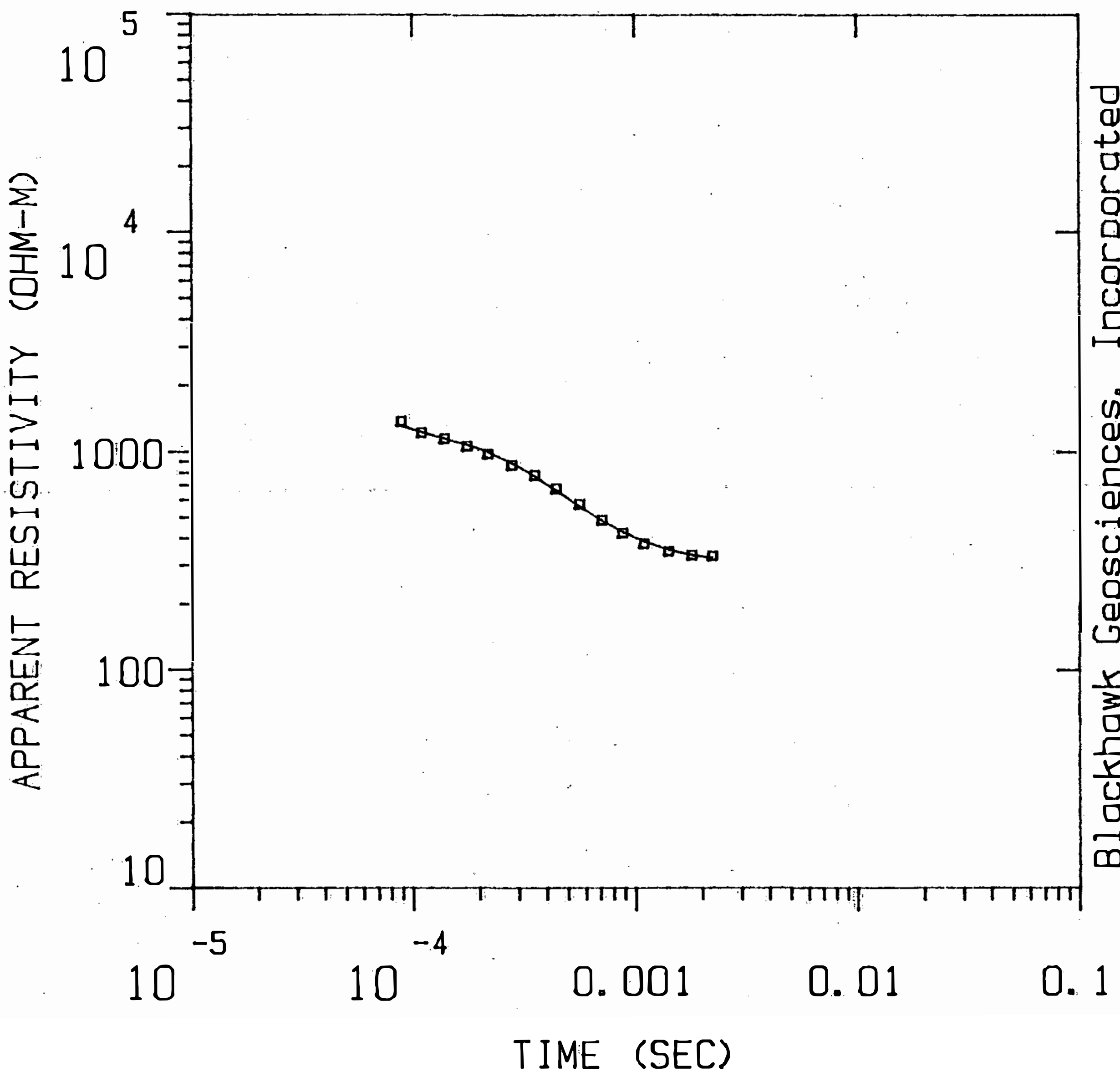
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 115.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.97						
P 2	0.00	0.00					
P 3	0.00	0.01	0.32				
P 4	0.00	0.00	0.02	0.00			
T 1	0.00	0.01	0.14	-0.02	0.69		
T 2	0.03	0.01	0.05	-0.01	0.31	0.17	
T 3	0.01	-0.01	-0.28	-0.03	-0.03	0.00	0.26

L1S750N



MODEL:

635. OHM-M	396. M
1820. OHM-M	46.5 M
56.2 OHM-M	95.5 M
642. OHM-M	

% ERROR: 2.99
CALIBRATION: 1
OFFSET: 76 M
RAMP: 115.0

L1S750N

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		493.8	1620.0		
634.66	395.5	98.2	322.3	0.6	0.6
1820.46	46.5	51.8	169.8	0.0	0.6
56.24	95.5	-43.7	-143.5	1.7	2.3
642.00					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.38E+03	1.32E+03	4.406	
2	1.10E-04	1.22E+03	1.23E+03	-0.716	
3	1.40E-04	1.14E+03	1.15E+03	-0.132	
4	1.77E-04	1.06E+03	1.07E+03	-1.341	
5	2.20E-04	9.71E+02	9.93E+02	-2.221	
6	2.80E-04	8.67E+02	8.89E+02	-2.522	
7	3.55E-04	7.79E+02	7.72E+02	0.897	
8	4.43E-04	6.75E+02	6.64E+02	1.637	
9	5.64E-04	5.73E+02	5.62E+02	2.101	
10	7.13E-04	4.85E+02	4.83E+02	0.461	
11	8.81E-04	4.22E+02	4.29E+02	-1.556	
12	1.10E-03	3.77E+02	3.87E+02	-2.670	
13	1.41E-03	3.48E+02	3.54E+02	-1.581	
14	1.80E-03	3.34E+02	3.34E+02	0.037	
15	2.22E-03	3.32E+02	3.24E+02	2.298	

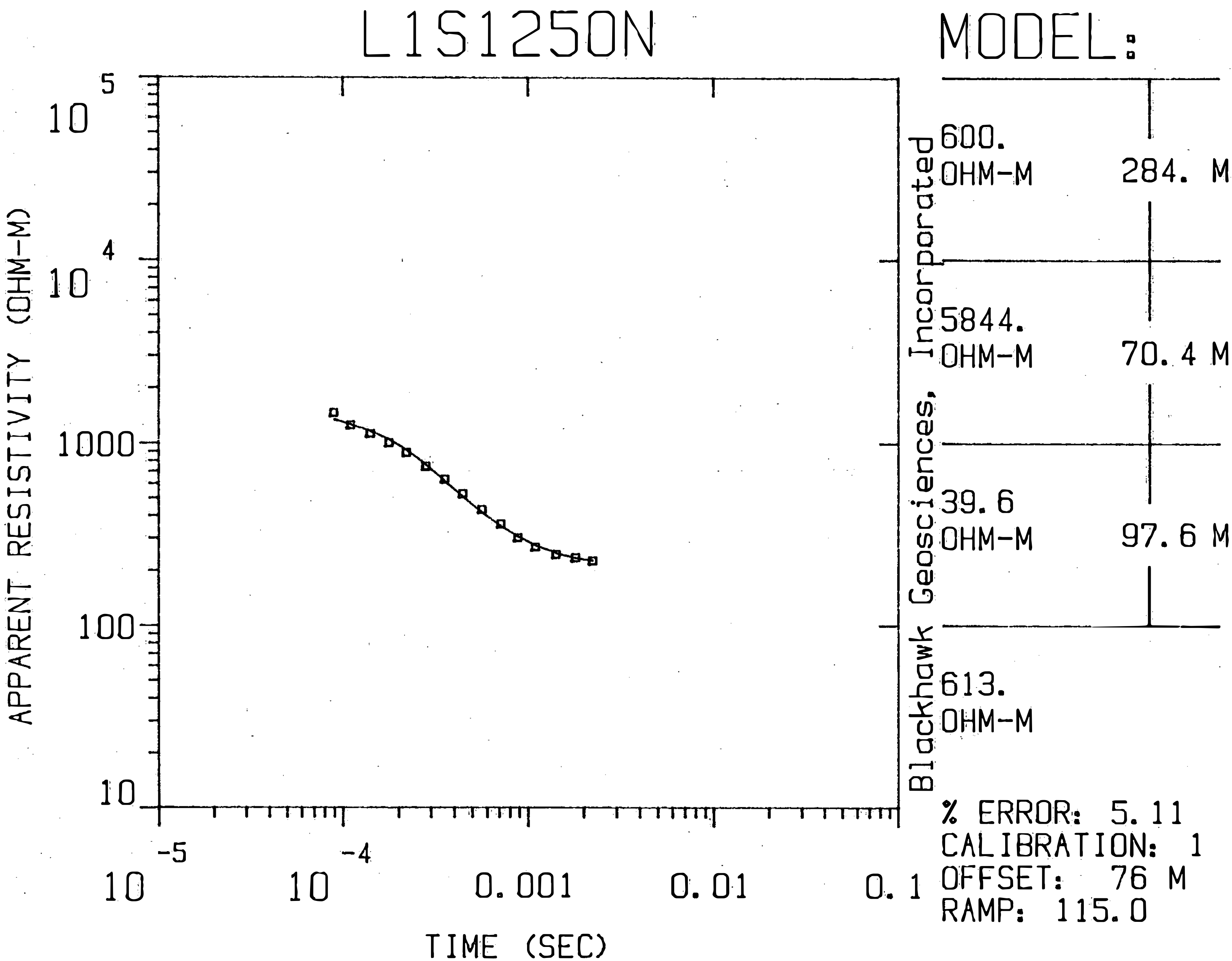
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 115.0 MICROSEC, DATA: L1S750N
3006 100N 750NZ OPR H 6 8 +100 000
Ch.21 = 0.115 Ch.22 = 0.089 Ch.23 = 17.5 Ch.24
RMS LOG ERROR: 1.28E-02, ANTILOG YIELDS 2.9928 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 115.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	1.00						
P 2	0.00	0.00					
P 3	0.00	0.00	0.59				
P 4	0.00	0.01	0.02	0.14			
T 1	0.00	0.00	0.06	-0.03	0.97		
T 2	0.01	0.01	-0.03	0.06	0.15	0.09	
T 3	0.00	-0.01	-0.46	-0.10	0.07	-0.02	0.45


L1S1250N
MODEL:
600.
OHM-M
284. M
5844.
OHM-M
70.4 M
39.6
OHM-M
97.6 M
613.
OHM-M
% ERROR: 5.11
CALIBRATION: 1
OFFSET: 76 M
RAMP: 115.0
Blackhawk Geosciences, Incorporated
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)

L1S1250N

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		487.7	1600.0		
600.38	283.8	203.9	669.0	0.5	0.5
5843.84	70.4	133.5	438.1	0.0	0.5
39.56	97.6	35.9	117.8	2.5	3.0
613.07					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.46E+03	1.34E+03	8.741	
2	1.10E-04	1.25E+03	1.26E+03	-0.701	
3	1.40E-04	1.13E+03	1.16E+03	-3.137	
4	1.77E-04	9.98E+02	1.05E+03	-4.605	
5	2.20E-04	8.83E+02	9.17E+02	-3.672	
6	2.80E-04	7.41E+02	7.62E+02	-2.808	
7	3.55E-04	6.31E+02	6.19E+02	1.942	
8	4.43E-04	5.24E+02	5.09E+02	2.941	
9	5.64E-04	4.31E+02	4.16E+02	3.528	
10	7.13E-04	3.59E+02	3.50E+02	2.464	
11	8.81E-04	3.01E+02	3.06E+02	-1.692	
12	1.10E-03	2.68E+02	2.74E+02	-2.100	
13	1.41E-03	2.44E+02	2.48E+02	-1.643	
14	1.80E-03	2.34E+02	2.32E+02	0.556	
15	2.22E-03	2.24E+02	2.25E+02	-0.125	

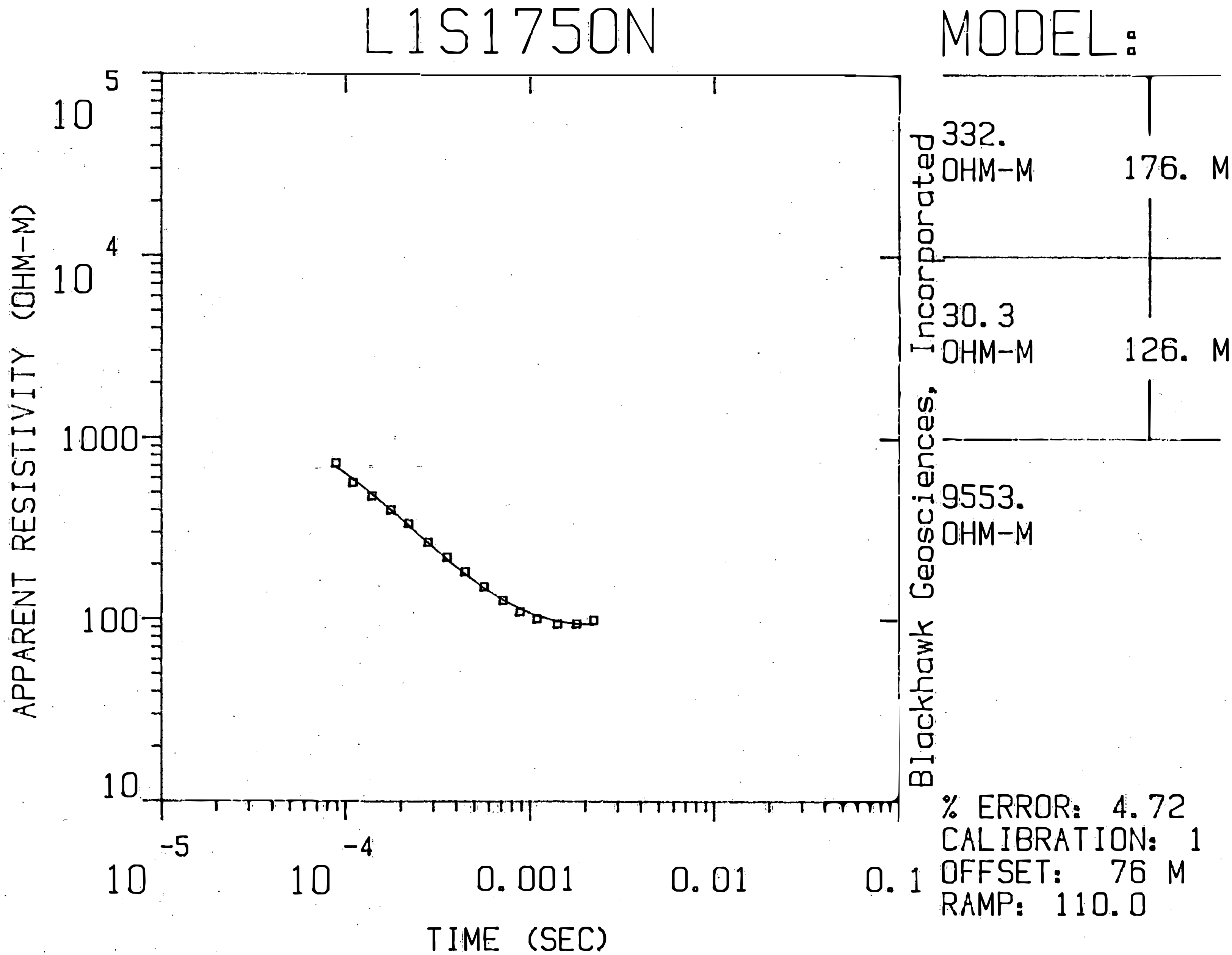
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 115.0 MICROSEC, DATA: L1S1250N
3006 100N 1250NZ OPR H 6 8 +100
Ch.21 = 0.115 Ch.22 = 0.089 Ch.23 = 17.5 Ch.24
RMS LOG ERROR: 2.17E-02, ANTILOG YIELDS 5.1127 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 115.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.93						
P 2	0.00	0.00					
P 3	-0.02	0.00	0.50				
P 4	0.00	0.00	0.03	0.00			
T 1	0.00	0.00	0.09	-0.01	0.87		
T 2	0.05	0.00	0.02	0.00	0.25	0.08	
T 3	0.00	0.00	-0.40	-0.03	0.06	0.01	0.35


L1S1750N
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
332.
OHM-M
176. M
30.3
OHM-M
126. M
9553.
OHM-M
% ERROR: 4.72
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S1750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		481.6	1580.0		
332.48	175.8	305.8	1003.1	0.5	0.5
30.30	126.1	179.6	589.3	4.2	4.7
9552.70					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	7.22E+02	6.91E+02	4.584	
2	1.10E-04	5.65E+02	5.92E+02	-4.596	
3	1.40E-04	4.75E+02	4.88E+02	-2.724	
4	1.77E-04	3.98E+02	3.99E+02	-0.305	
5	2.20E-04	3.36E+02	3.29E+02	2.142	
6	2.80E-04	2.65E+02	2.64E+02	0.204	
7	3.55E-04	2.20E+02	2.14E+02	2.640	
8	4.43E-04	1.82E+02	1.78E+02	2.498	
9	5.64E-04	1.50E+02	1.48E+02	1.387	
10	7.13E-04	1.27E+02	1.28E+02	-0.619	
11	8.81E-04	1.10E+02	1.14E+02	-3.810	
12	1.10E-03	1.01E+02	1.04E+02	-3.753	
13	1.41E-03	9.40E+01	9.73E+01	-3.347	
14	1.80E-03	9.41E+01	9.39E+01	0.181	
15	2.22E-03	9.88E+01	9.34E+01	5.730	

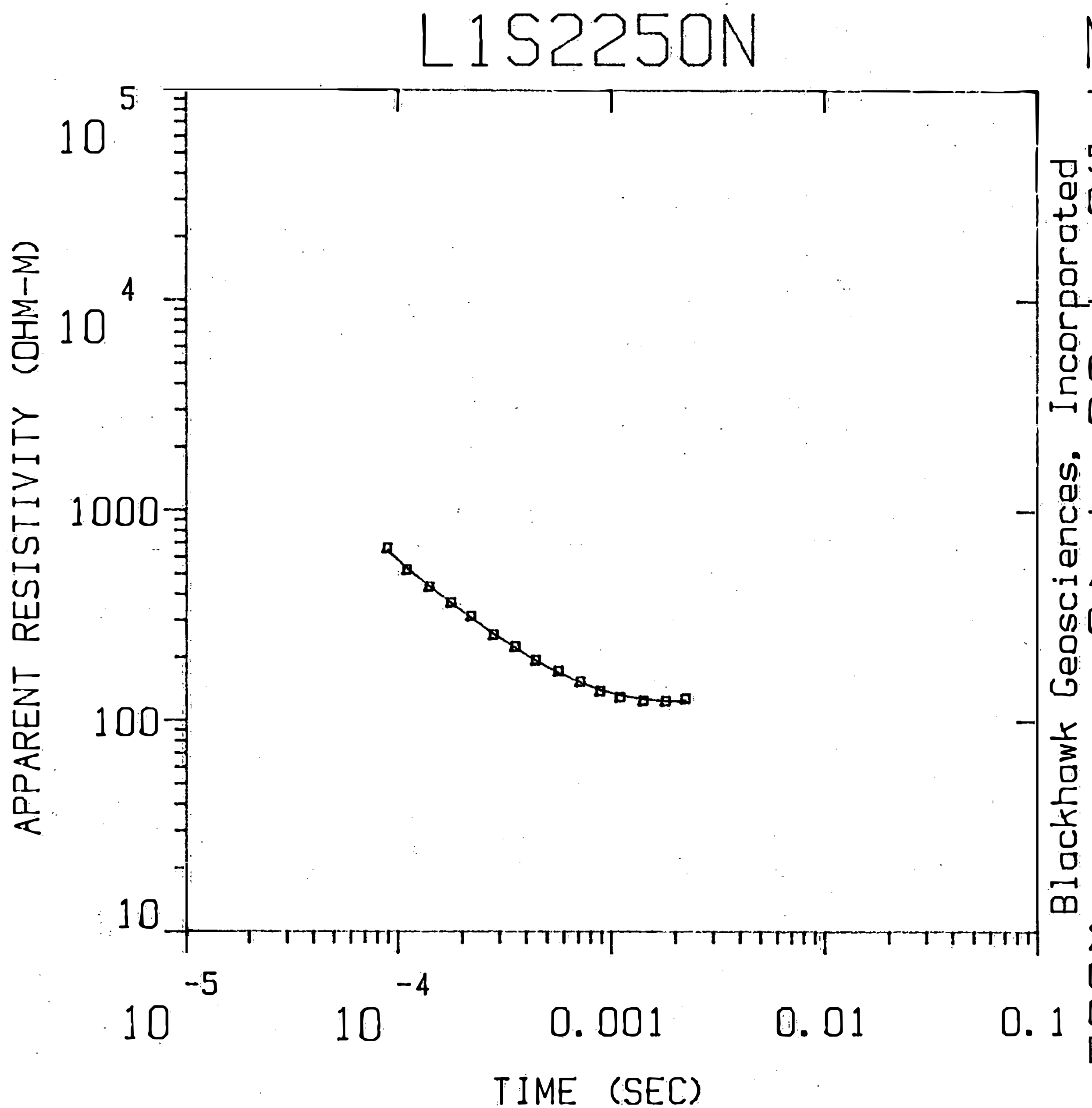
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S1750N
0107 100N 1750NZ OPR H 6 8 +100 52*152
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.00E-02, ANTILOG YIELDS 4.7241 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	-0.01	0.00	1.00
	P 1	P 2	P 3	T 1	T 2



MODEL:

540.
OHM-M 131. M

65.0
OHM-M 222. M

486.
OHM-M

% ERROR: 2.37
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S2250N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		472.4	1550.0		
540.04	130.5	341.9	1121.8	0.2	0.2
65.01	222.1	119.8	393.1	3.4	3.7
486.32					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	6.60E+02	6.46E+02	2.187	
2	1.10E-04	5.21E+02	5.36E+02	-2.680	
3	1.40E-04	4.33E+02	4.37E+02	-0.914	
4	1.77E-04	3.64E+02	3.63E+02	0.280	
5	2.20E-04	3.13E+02	3.08E+02	1.577	
6	2.80E-04	2.55E+02	2.59E+02	-1.447	
7	3.55E-04	2.24E+02	2.21E+02	1.166	
8	4.43E-04	1.94E+02	1.93E+02	0.427	
9	5.64E-04	1.72E+02	1.69E+02	1.818	
10	7.13E-04	1.53E+02	1.52E+02	0.599	
11	8.81E-04	1.38E+02	1.40E+02	-1.355	
12	1.10E-03	1.29E+02	1.32E+02	-2.193	
13	1.41E-03	1.25E+02	1.27E+02	-1.563	
14	1.80E-03	1.24E+02	1.24E+02	0.485	
15	2.22E-03	1.28E+02	1.25E+02	2.137	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S2250N
0107 100N 2250NZ OPR H 6 8 +100
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.02E-02, ANTILOG YIELDS 2.3720 %
LATE TIME PARAMETERS

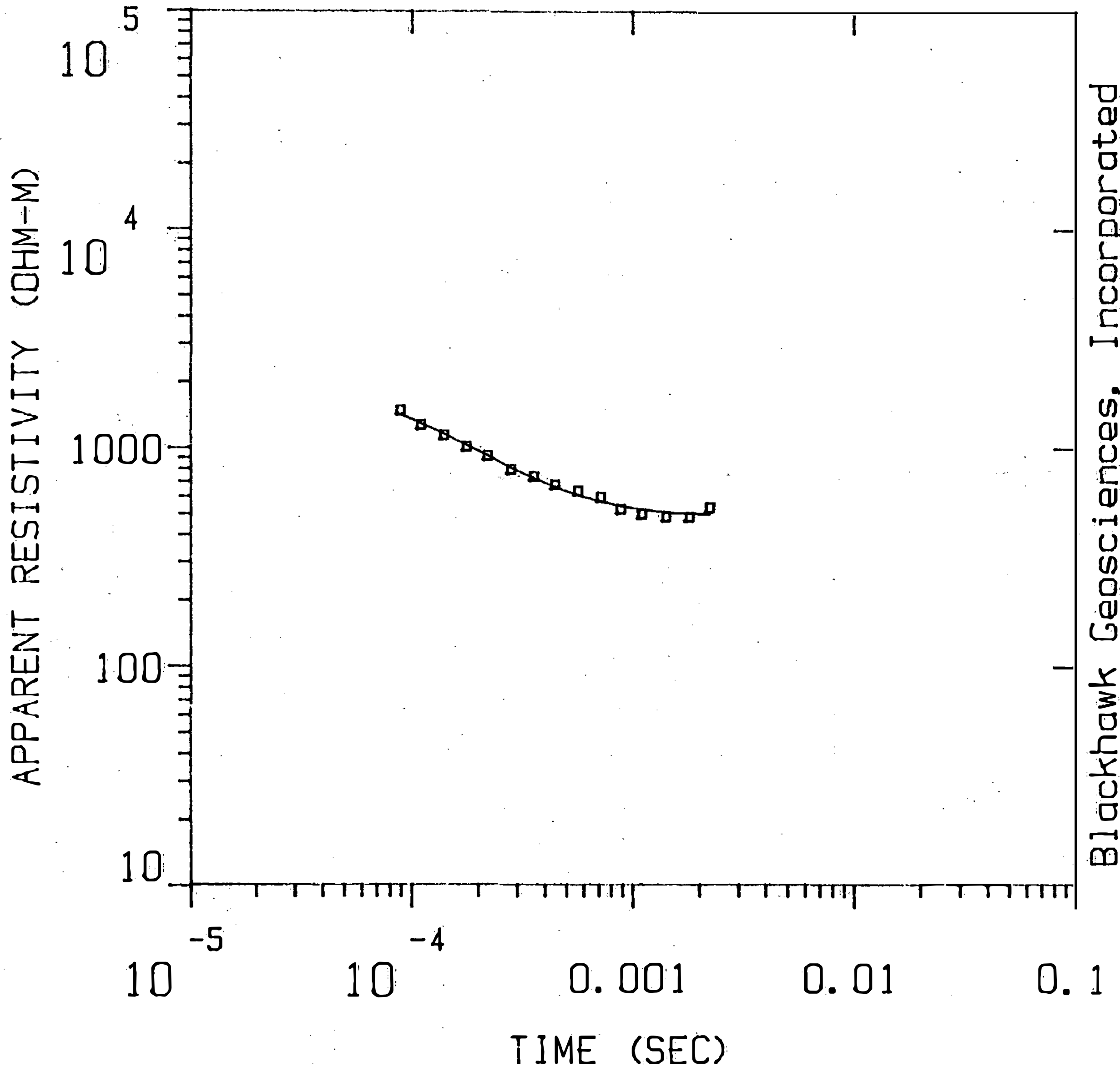
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.59				
P 2	-0.04	0.99			
P 3	0.00	-0.02	0.04		
T 1	0.09	0.01	0.00	0.98	
T 2	-0.10	-0.03	-0.09	0.03	0.92
	P 1	P 2	P 3	T 1	T 2

L1S2750N



MODEL:

705.
OHM-M 390. M

73.9
OHM-M 34.7 M

531.
OHM-M

% ERROR: 5.69
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S2750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		481.6	1580.0		
705.28	389.8	91.7	301.0	0.6	0.6
73.86	34.7	57.1	187.2	0.5	1.0
531.43					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.49E+03	1.43E+03	4.194	
2	1.10E-04	1.27E+03	1.30E+03	-1.984	
3	1.40E-04	1.14E+03	1.16E+03	-1.764	
4	1.77E-04	1.01E+03	1.03E+03	-1.887	
5	2.20E-04	9.19E+02	9.23E+02	-0.378	
6	2.80E-04	7.97E+02	8.15E+02	-2.279	
7	3.55E-04	7.42E+02	7.28E+02	1.887	
8	4.43E-04	6.78E+02	6.63E+02	2.153	
9	5.64E-04	6.35E+02	6.09E+02	4.292	
10	7.13E-04	5.95E+02	5.69E+02	4.459	
11	8.81E-04	5.25E+02	5.43E+02	-3.358	
12	1.10E-03	4.98E+02	5.23E+02	-4.799	
13	1.41E-03	4.85E+02	5.08E+02	-4.569	
14	1.80E-03	4.84E+02	5.00E+02	-3.270	
15	2.22E-03	5.36E+02	4.97E+02	7.861	

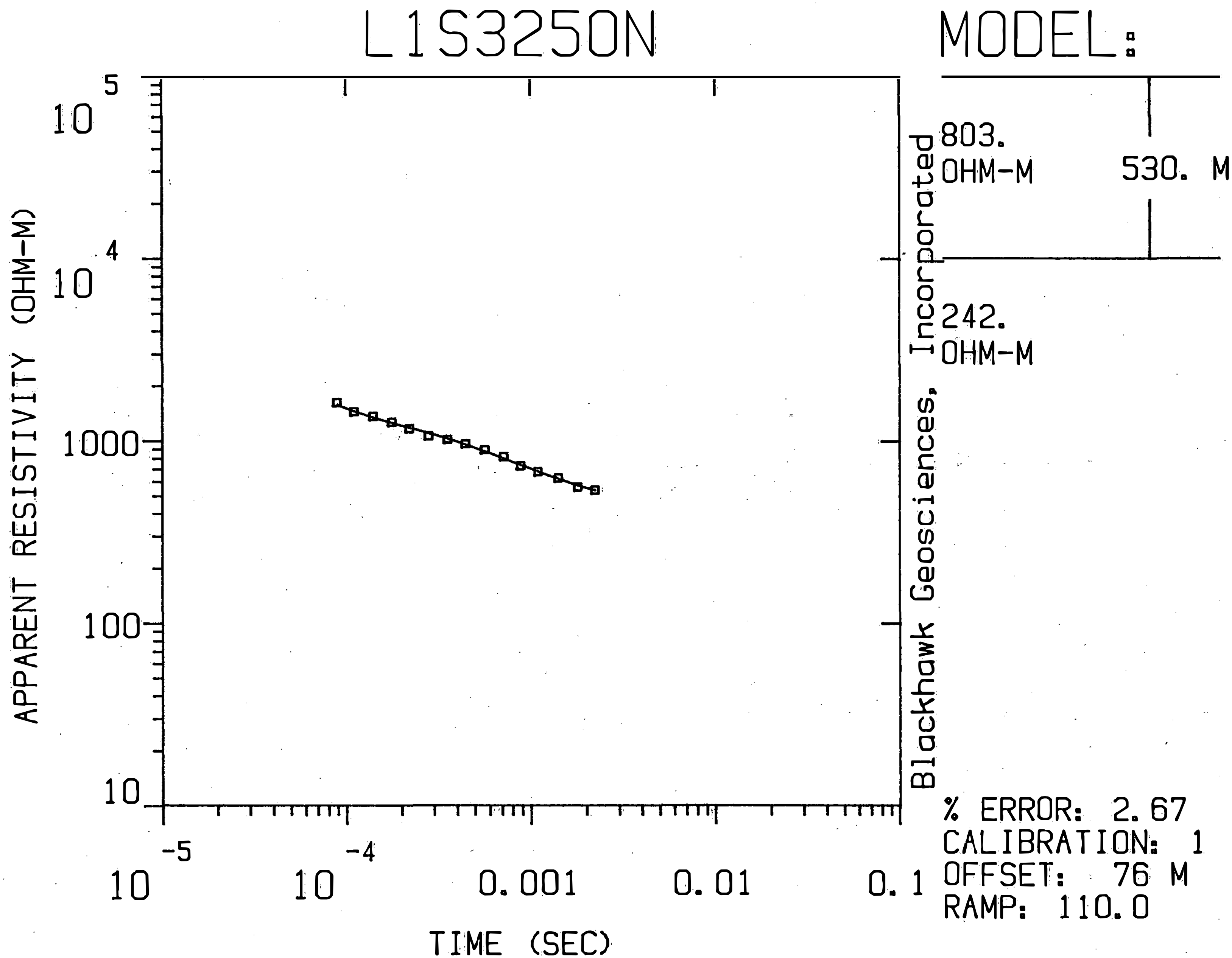
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S2750N
0107 100N 2750NZ OPR H 6 8 +100
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.40E-02, ANTILOG YIELDS 5.6864 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	1.00				
P 2	-0.01	0.48			
P 3	0.01	0.07	0.87		
T 1	0.00	0.05	-0.04	0.98	
T 2	0.00	-0.45	-0.07	0.01	0.43



L1S3250N
MODEL:
803.
OHM-M
530. M
242.
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 2.67
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S3250N

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		490.7	1610.0		
802.92	530.0	-39.2	-128.7	0.7	0.7
242.20					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.62E+03	1.58E+03	2.659	
2	1.10E-04	1.44E+03	1.46E+03	-0.939	
3	1.40E-04	1.36E+03	1.34E+03	1.407	
4	1.77E-04	1.26E+03	1.25E+03	0.892	
5	2.20E-04	1.16E+03	1.18E+03	-1.233	
6	2.80E-04	1.06E+03	1.10E+03	-3.867	
7	3.55E-04	1.01E+03	1.03E+03	-1.186	
8	4.43E-04	9.60E+02	9.54E+02	0.580	
9	5.64E-04	8.92E+02	8.75E+02	1.955	
10	7.13E-04	8.17E+02	8.00E+02	2.073	
11	8.81E-04	7.28E+02	7.38E+02	-1.338	
12	1.10E-03	6.76E+02	6.79E+02	-0.385	
13	1.41E-03	6.26E+02	6.19E+02	1.063	
14	1.80E-03	5.58E+02	5.71E+02	-2.269	
15	2.22E-03	5.39E+02	5.35E+02	0.670	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S3250N
0207 100N 3250NZ OPR H 6 8 +100 52*152
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.14E-02, ANTILOG YIELDS 2.6652 %
LATE TIME PARAMETERS

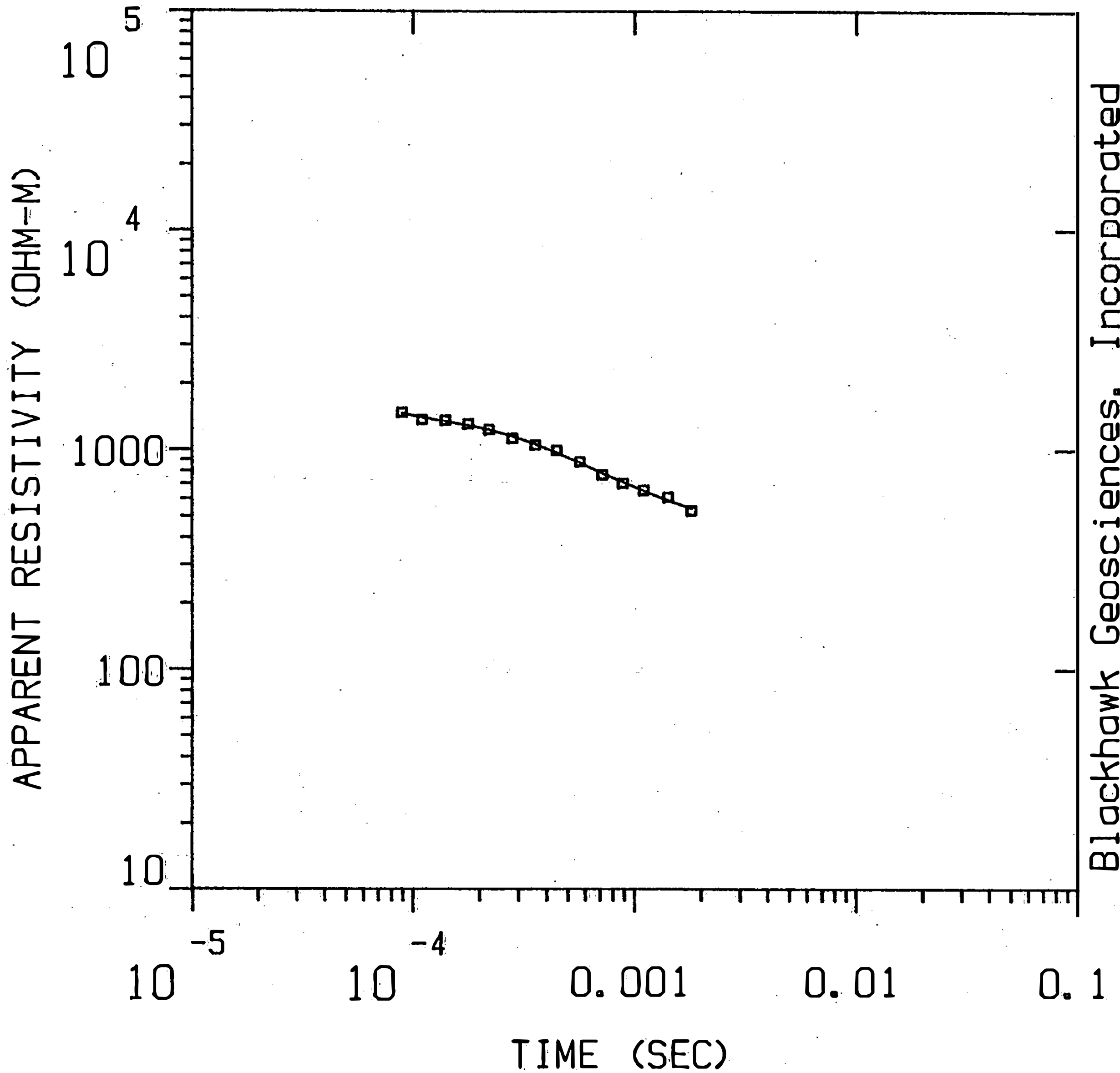
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.97		
P 2	-0.03	0.30	
T 1	0.03	0.22	0.83
	P 1	P 2	T 1

L1S3750N



MODEL:

649. OHM-M 205. M

4103. OHM-M 231. M

231. OHM-M

% ERROR: 2.72
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S3750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		496.8	1630.0		
648.69	204.6	292.2	958.8	0.3	0.3
4102.52	231.4	60.8	199.6	0.1	0.4
231.05					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.47E+03	1.46E+03	0.745	
2	1.10E-04	1.37E+03	1.40E+03	-2.242	
3	1.40E-04	1.36E+03	1.34E+03	1.173	
4	1.77E-04	1.31E+03	1.29E+03	1.574	
5	2.20E-04	1.23E+03	1.23E+03	0.059	
6	2.80E-04	1.12E+03	1.15E+03	-2.224	
7	3.55E-04	1.05E+03	1.06E+03	-0.905	
8	4.43E-04	9.91E+02	9.65E+02	2.644	
9	5.64E-04	8.76E+02	8.68E+02	0.971	
10	7.13E-04	7.66E+02	7.81E+02	-1.893	
11	8.81E-04	7.01E+02	7.11E+02	-1.471	
12	1.10E-03	6.52E+02	6.49E+02	0.570	
13	1.41E-03	6.07E+02	5.88E+02	3.328	
14	1.80E-03	5.29E+02	5.40E+02	-2.143	

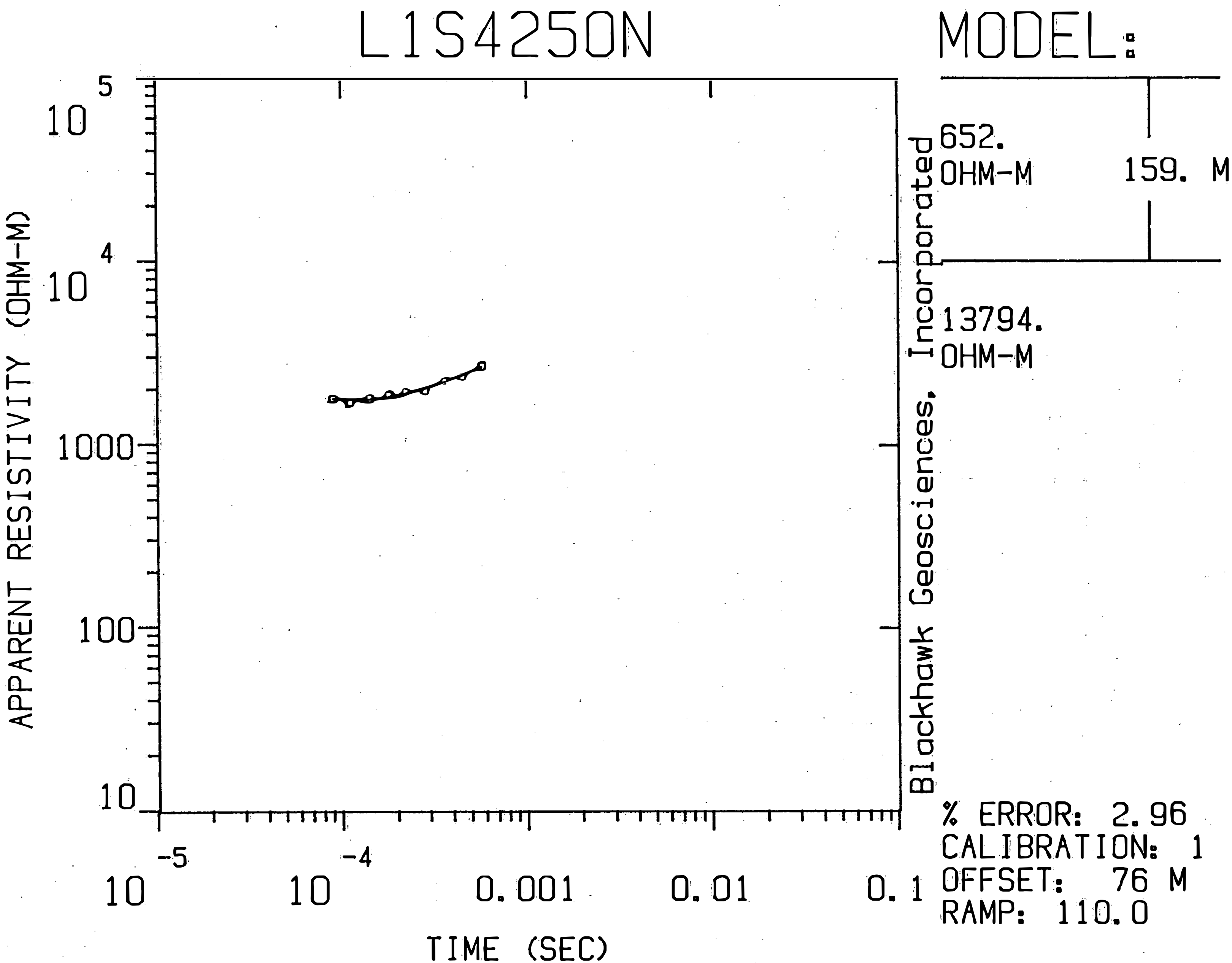
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 14 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S3750N
0207 100N 3750NZ OPR H 6 8 +100
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.16E-02, ANTILOG YIELDS 2.7166 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.85				
P 2	0.04	0.01			
P 3	0.04	0.00	0.41		
T 1	-0.27	0.00	0.20	0.33	
T 2	0.15	0.05	0.19	0.25	0.64
	P 1	P 2	P 3	T 1	T 2


L1S4250N
MODEL:
652.
OHM-M
159. M
13794.
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 2.96
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S4250N

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		496.8	1630.0		
651.70	159.1	337.7	1107.9	0.2	0.2
13794.27					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.77E+03	1.75E+03	0.771	
2	1.10E-04	1.69E+03	1.74E+03	-2.820	
3	1.40E-04	1.77E+03	1.75E+03	0.830	
4	1.77E-04	1.85E+03	1.81E+03	2.699	
5	2.20E-04	1.92E+03	1.89E+03	1.838	
6	2.80E-04	1.95E+03	2.01E+03	-3.312	
7	3.55E-04	2.19E+03	2.18E+03	0.465	
8	4.43E-04	2.35E+03	2.38E+03	-1.197	
9	5.64E-04	2.67E+03	2.64E+03	1.047	

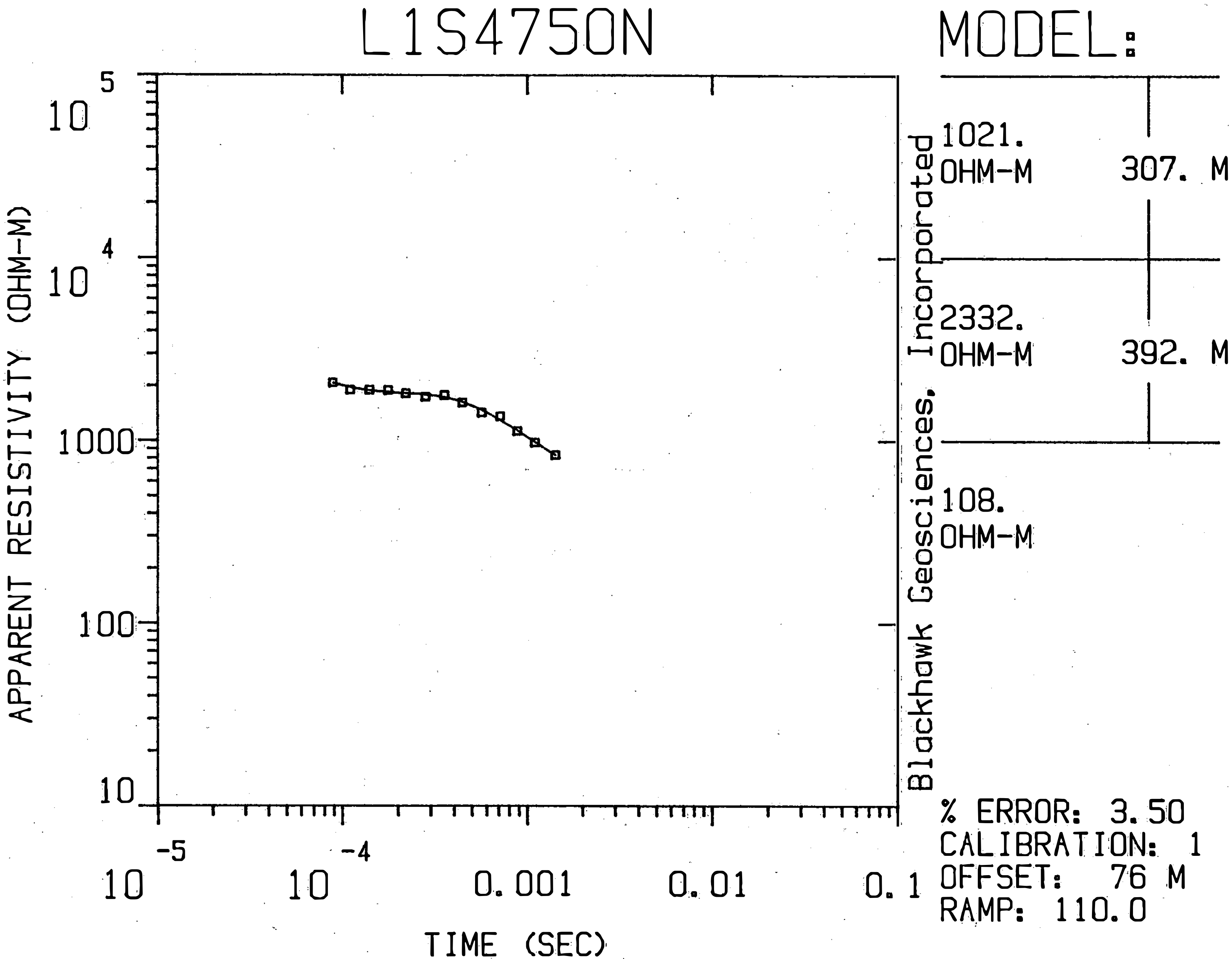
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 9 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S4250N
0207 100N 4250NZ OPR H 6 8 +100
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.27E-02, ANTILOG YIELDS 2.9565 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.32		
P 2	0.02	0.00	
T 1	-0.24	-0.02	0.18
	P 1	P 2	T 1



L1S4750N
MODEL:
1021.
OHM-M
307. M
2332.
OHM-M
392. M
108.
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 3.50
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S4750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		499.9	1640.0		
1020.56	306.6	193.3	634.2	0.3	0.3
2332.44	392.4	-199.1	-653.2	0.2	0.5
107.55					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.07E+03	2.07E+03	0.106	
2	1.10E-04	1.90E+03	1.96E+03	-3.124	
3	1.40E-04	1.89E+03	1.88E+03	0.852	
4	1.77E-04	1.89E+03	1.84E+03	2.853	
5	2.20E-04	1.82E+03	1.81E+03	0.192	
6	2.80E-04	1.74E+03	1.79E+03	-2.617	
7	3.55E-04	1.78E+03	1.73E+03	2.482	
8	4.43E-04	1.62E+03	1.64E+03	-1.003	
9	5.64E-04	1.43E+03	1.48E+03	-3.606	
10	7.13E-04	1.36E+03	1.30E+03	4.640	
11	8.81E-04	1.13E+03	1.14E+03	-0.788	
12	1.10E-03	9.75E+02	9.84E+02	-0.911	
13	1.41E-03	8.34E+02	8.31E+02	0.269	

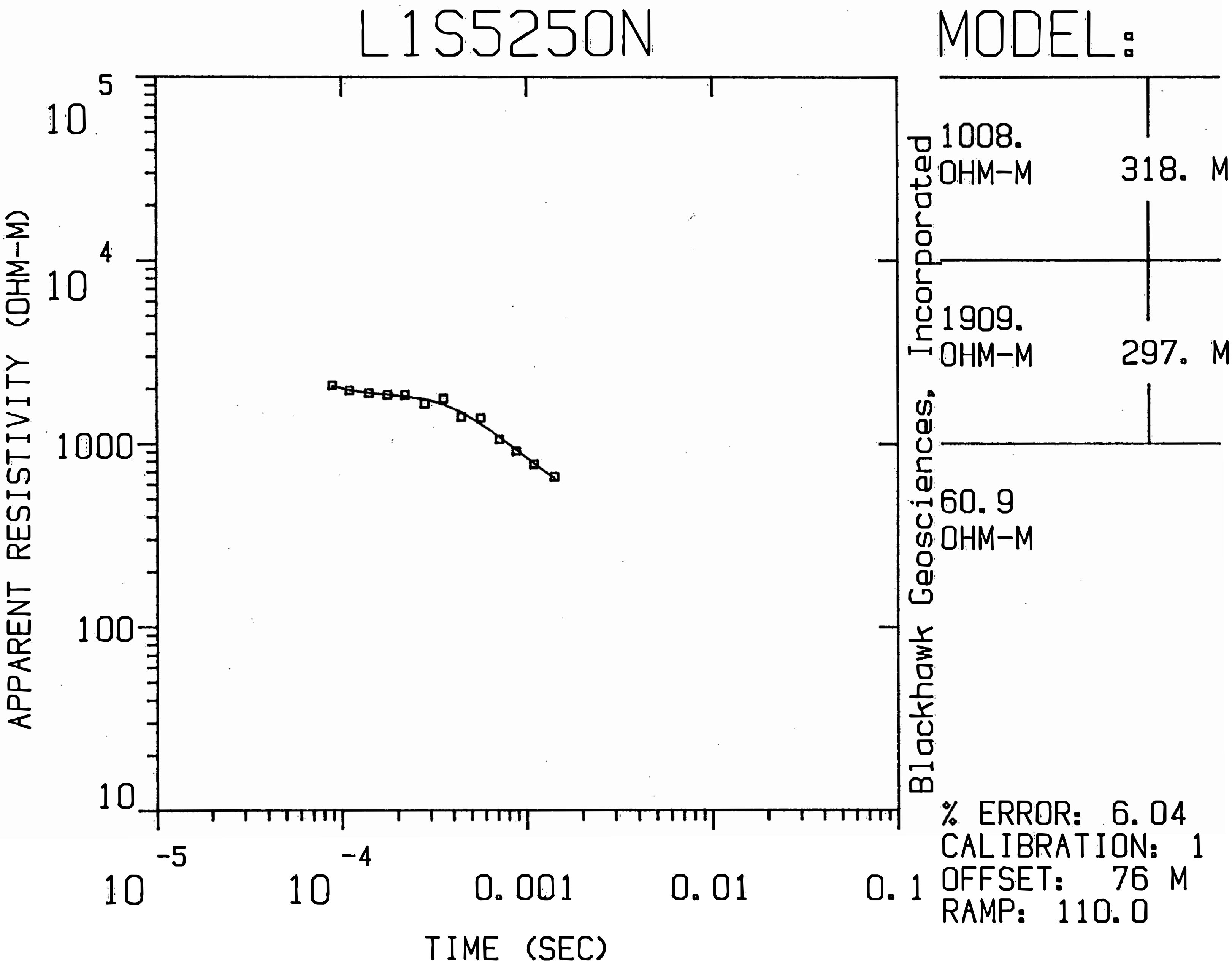
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 13 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S4750N
1207 100N 4750NZ OPR H 6 8 +TXL=152*152
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18.2 Ch.24 =
RMS LOG ERROR: 1.49E-02, ANTILOG YIELDS 3.5007 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.99				
P 2	0.00	0.21			
P 3	0.03	-0.10	0.61		
T 1	-0.04	-0.25	0.13	0.76	
T 2	0.03	0.25	-0.08	0.19	0.84


L1S5250N
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
1008.
OHM-M
318. M
1909.
OHM-M
297. M
60.9
OHM-M
% ERROR: 6.04
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S5250N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		499.9	1640.0		
1008.08	318.3	181.5	595.6	0.3	0.3
1909.47	296.9	-115.4	-378.6	0.2	0.5
60.89					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.08E+03	2.07E+03	0.543	
2	1.10E-04	1.96E+03	1.97E+03	-0.528	
3	1.40E-04	1.89E+03	1.89E+03	0.010	
4	1.77E-04	1.85E+03	1.85E+03	0.074	
5	2.20E-04	1.85E+03	1.81E+03	1.900	
6	2.80E-04	1.65E+03	1.75E+03	-5.887	
7	3.55E-04	1.77E+03	1.65E+03	7.360	
8	4.43E-04	1.40E+03	1.49E+03	-5.817	
9	5.64E-04	1.38E+03	1.29E+03	7.445	
10	7.13E-04	1.06E+03	1.09E+03	-3.068	
11	8.81E-04	9.09E+02	9.25E+02	-1.741	
12	1.10E-03	7.70E+02	7.81E+02	-1.440	
13	1.41E-03	6.59E+02	6.45E+02	2.278	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 13 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S5250N
1207 100N 5250NZ OPR H 6 8 +
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18.2 Ch.24 =
RMS LOG ERROR: 2.55E-02, ANTILOG YIELDS 6.0416 %
LATE TIME PARAMETERS

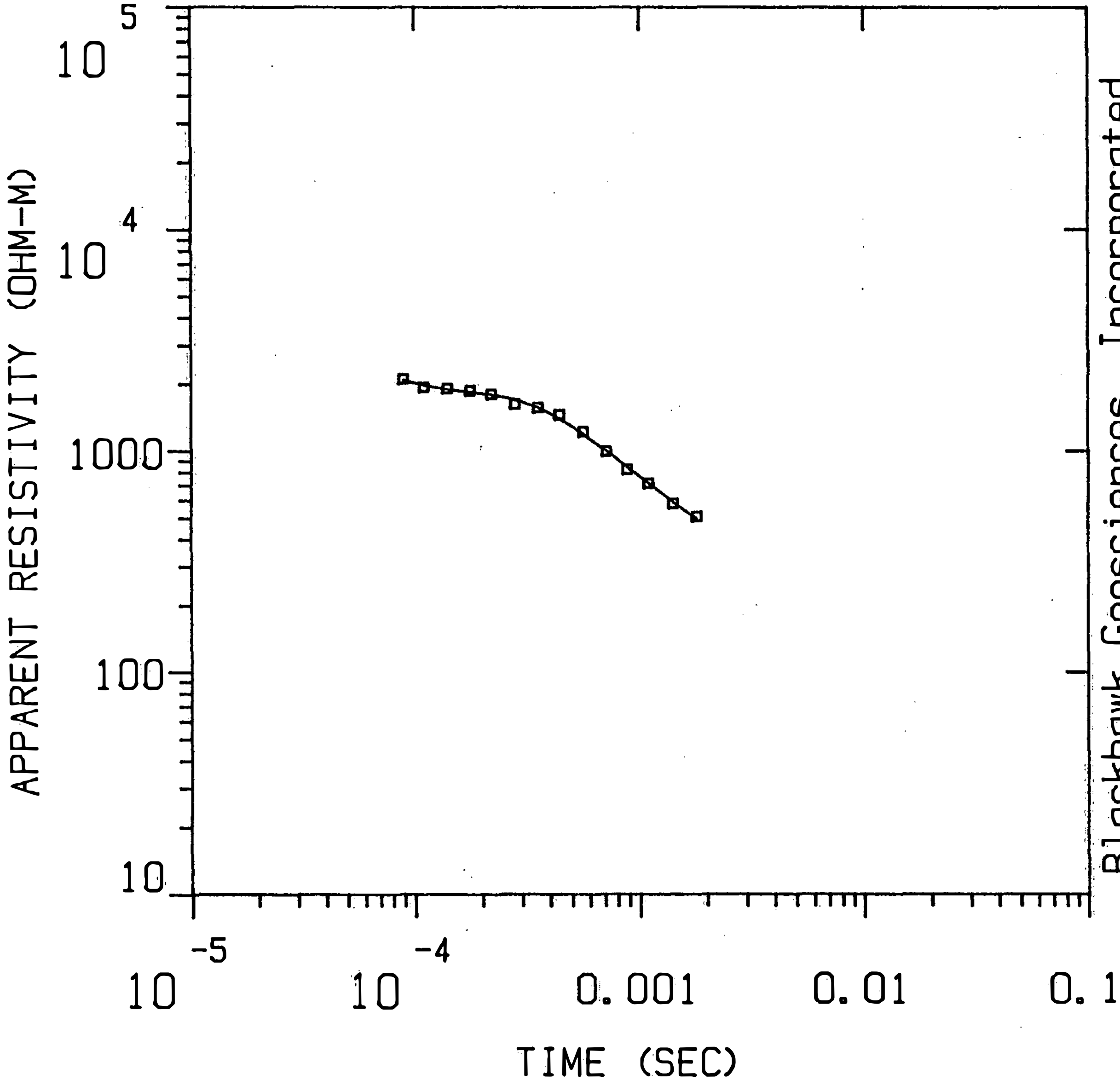
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.99				
P 2	0.02	0.19			
P 3	0.02	-0.12	0.66		
T 1	-0.03	-0.18	0.15	0.74	
T 2	0.03	0.23	-0.14	0.27	0.71
	P 1	P 2	P 3	T 1	T 2

L1S575ON



MODEL:

1006. OHM-M	301. M
1433. OHM-M	287. M
55.9 OHM-M	

% ERROR: 3.37
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S5750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		499.9	1640.0		
1006.12	300.6	199.3	653.9	0.3	0.3
1433.45	286.6	-87.3	-286.4	0.2	0.5
55.89					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.10E+03	2.08E+03	1.110	
2	1.10E-04	1.93E+03	1.97E+03	-2.127	
3	1.40E-04	1.91E+03	1.89E+03	0.854	
4	1.77E-04	1.87E+03	1.84E+03	1.703	
5	2.20E-04	1.80E+03	1.79E+03	0.810	
6	2.80E-04	1.62E+03	1.70E+03	-4.680	
7	3.55E-04	1.56E+03	1.57E+03	-0.169	
8	4.43E-04	1.45E+03	1.40E+03	3.819	
9	5.64E-04	1.22E+03	1.19E+03	2.155	
10	7.13E-04	9.93E+02	1.00E+03	-0.814	
11	8.81E-04	8.23E+02	8.48E+02	-2.895	
12	1.10E-03	7.13E+02	7.14E+02	-0.182	
13	1.41E-03	5.80E+02	5.89E+02	-1.500	
14	1.80E-03	5.06E+02	4.95E+02	2.271	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 14 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S5750N
1307 100N 5750NZ OPR H 6 8 +TXL=152*152
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.44E-02, ANTILOG YIELDS 3.3693 %
LATE TIME PARAMETERS

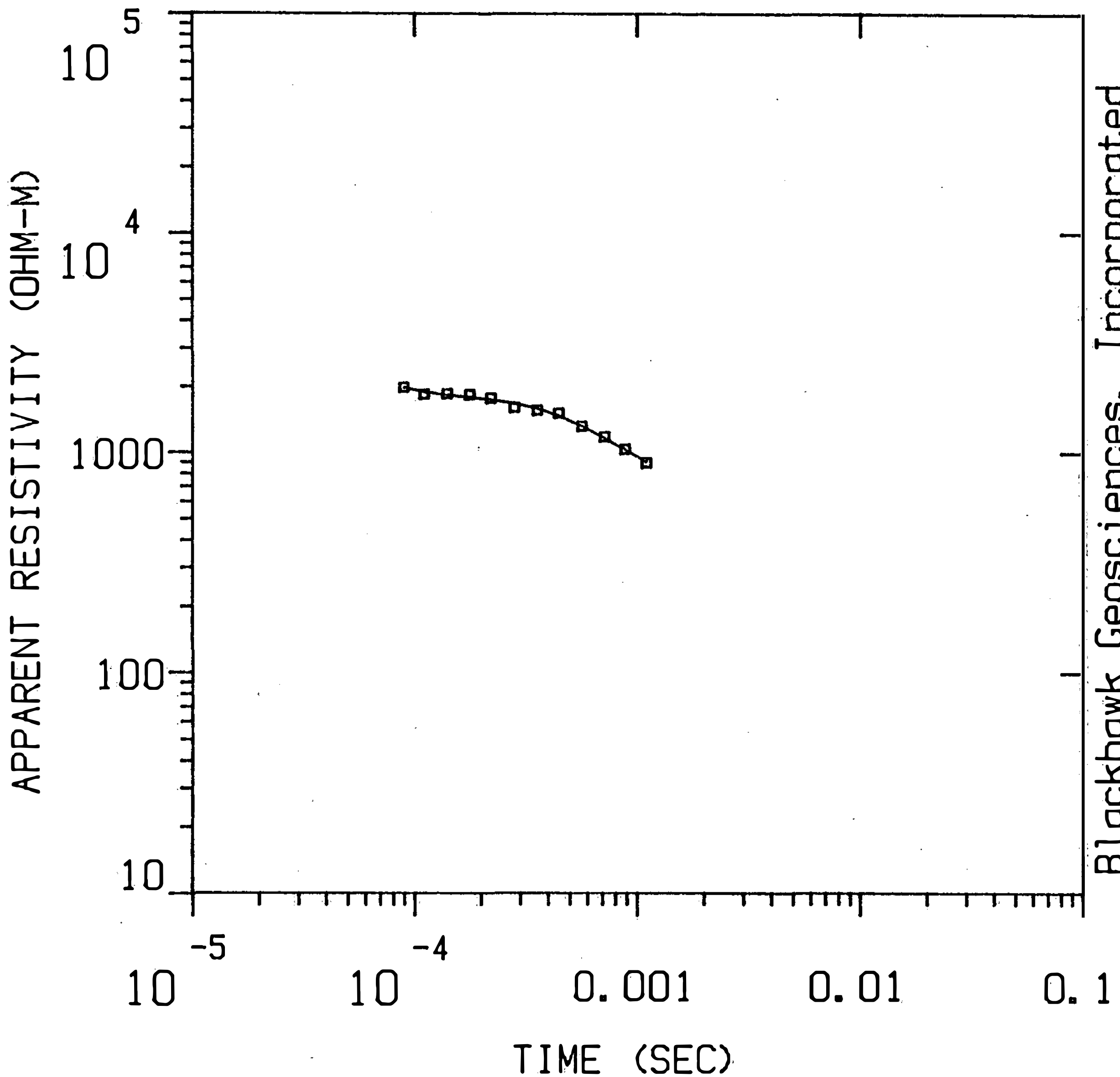
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.93				
P 2	0.10	0.05			
P 3	-0.05	-0.06	0.13		
T 1	-0.07	0.00	0.03	0.49	
T 2	0.06	0.06	-0.03	0.46	0.49
	P 1	P 2	P 3	T 1	T 2

L1S6250N



MODEL:

871. OHM-M

187. M

1805. OHM-M

456. M

163. OHM-M

% ERROR: 3.27
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S6250N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		518.2	1700.0		
870.97	187.0	331.1	1086.3	0.2	0.2
1805.44	456.4	-125.3	-411.0	0.3	0.5
163.25					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.97E+03	1.97E+03	0.150	
2	1.10E-04	1.83E+03	1.88E+03	-2.593	
3	1.40E-04	1.84E+03	1.81E+03	1.487	
4	1.77E-04	1.82E+03	1.77E+03	3.218	
5	2.20E-04	1.76E+03	1.73E+03	1.626	
6	2.80E-04	1.60E+03	1.67E+03	-4.264	
7	3.55E-04	1.56E+03	1.59E+03	-1.939	
8	4.43E-04	1.51E+03	1.47E+03	2.739	
9	5.64E-04	1.32E+03	1.32E+03	-0.209	
10	7.13E-04	1.18E+03	1.16E+03	1.251	
11	8.81E-04	1.04E+03	1.03E+03	0.379	
12	1.10E-03	8.97E+02	9.08E+02	-1.246	

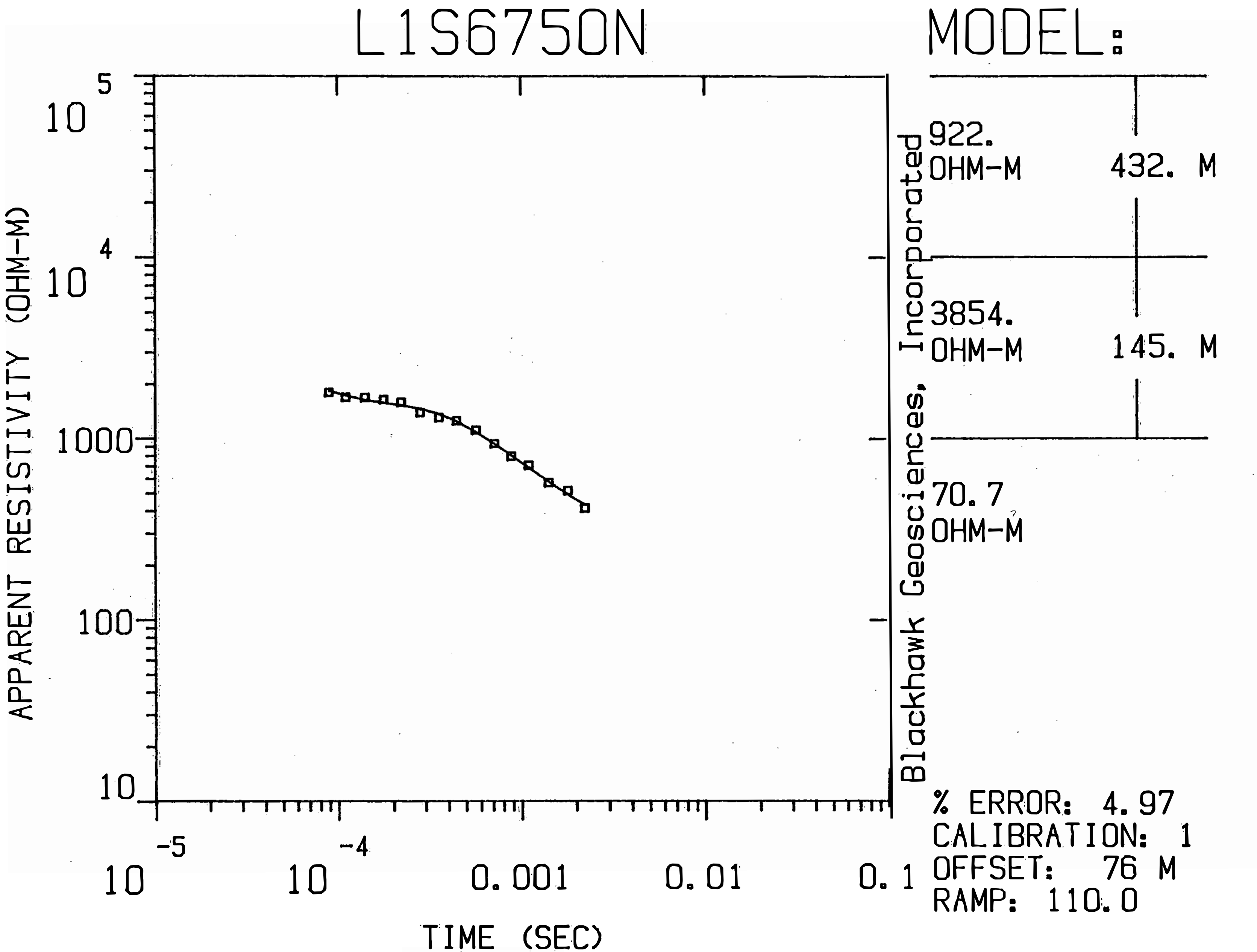
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 12 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S6250N
1307 100N 6250NZ OPR H 6 8 +:5756250N
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 1.40E-02, ANTILOG YIELDS 3.2682 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.95				
P 2	-0.03	0.61			
P 3	0.05	-0.16	0.66		
T 1	-0.16	-0.31	0.07	0.38	
T 2	0.06	0.19	0.03	0.27	0.87
	P 1	P 2	P 3	T 1	T 2


L1S6750N
MODEL:
APPARENT RESISTIVITY (OHM-M)
10 5
10 4
1000
100
10
10 -5
10 -4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
922.
OHM-M
432. M
3854.
OHM-M
145. M
70.7
OHM-M
% ERROR: 4.97
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S6750N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		527.3	1730.0		
922.07	431.6	95.7	314.1	0.5	0.5
3853.81	145.2	-49.5	-162.4	0.0	0.5
70.66					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.80E+03	1.84E+03	-2.528	
2	1.10E-04	1.69E+03	1.73E+03	-2.230	
3	1.40E-04	1.68E+03	1.64E+03	2.962	
4	1.77E-04	1.64E+03	1.57E+03	4.400	
5	2.20E-04	1.59E+03	1.53E+03	4.044	
6	2.80E-04	1.39E+03	1.46E+03	-4.893	
7	3.55E-04	1.31E+03	1.37E+03	-4.527	
8	4.43E-04	1.25E+03	1.25E+03	0.473	
9	5.64E-04	1.11E+03	1.09E+03	1.834	
10	7.13E-04	9.36E+02	9.36E+02	0.003	
11	8.81E-04	7.96E+02	8.06E+02	-1.209	
12	1.10E-03	7.10E+02	6.90E+02	2.903	
13	1.41E-03	5.70E+02	5.78E+02	-1.330	
14	1.80E-03	5.16E+02	4.93E+02	4.751	
15	2.22E-03	4.13E+02	4.32E+02	-4.303	

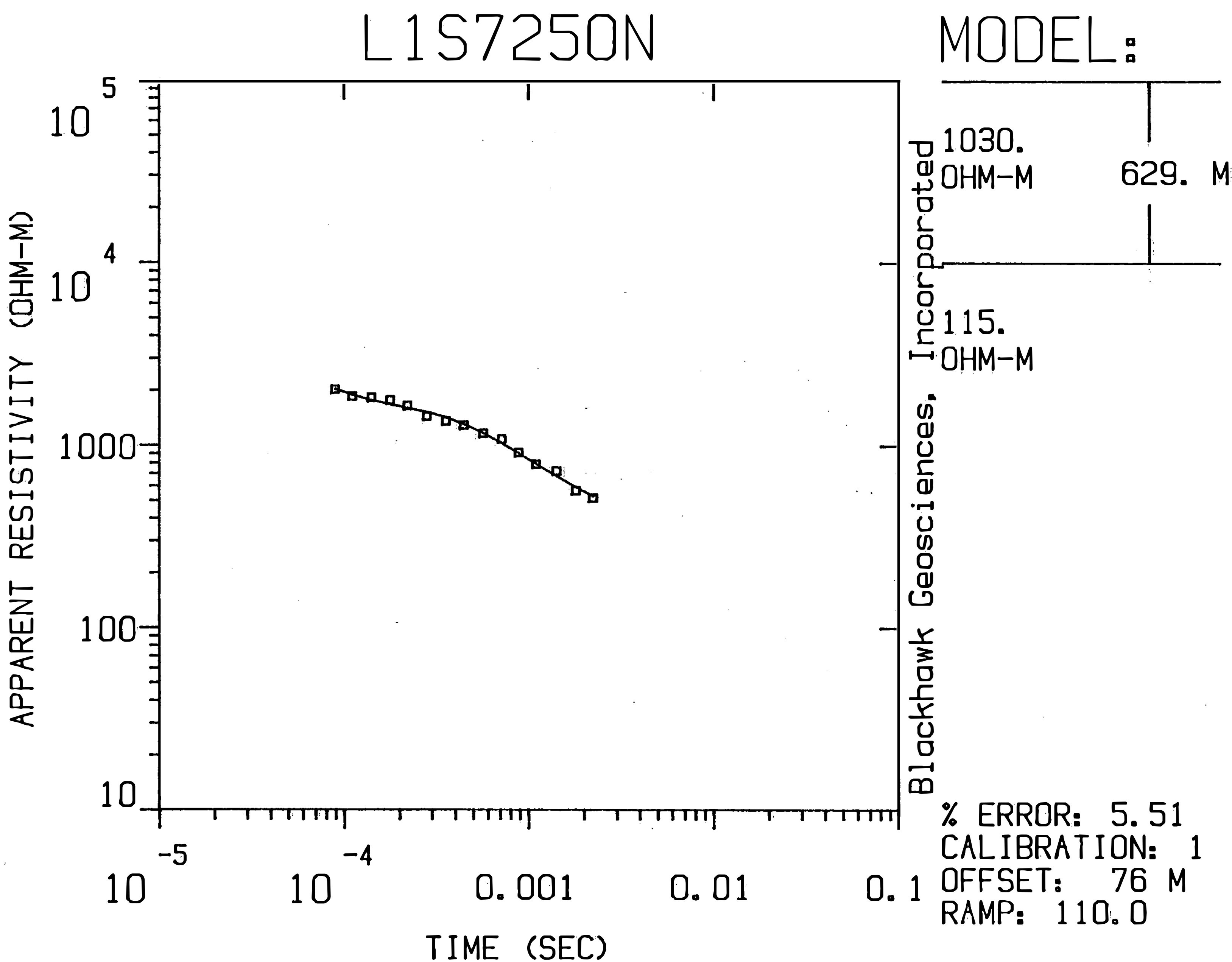
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S6750N
1307 100N 6750NZ OPR H 6 8 +
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.11E-02, ANTILOG YIELDS 4.9713 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.96				
P 2	0.01	0.00			
P 3	-0.04	-0.01	0.15		
T 1	-0.01	0.01	0.07	0.83	
T 2	0.05	0.01	-0.03	0.31	0.16
	P 1	P 2	P 3	T 1	T 2



L1S7250N
MODEL:
1030.
OHM-M
629. M
115.
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 5.51
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S7250N

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		527.3	1730.0		
1030.42	629.0	-101.7	-333.8	0.6	0.6
115.47					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.02E+03	2.04E+03	-1.110	
2	1.10E-04	1.85E+03	1.89E+03	-2.106	
3	1.40E-04	1.83E+03	1.77E+03	3.336	
4	1.77E-04	1.77E+03	1.68E+03	5.448	
5	2.20E-04	1.65E+03	1.60E+03	2.771	
6	2.80E-04	1.45E+03	1.52E+03	-5.090	
7	3.55E-04	1.36E+03	1.43E+03	-4.644	
8	4.43E-04	1.29E+03	1.32E+03	-1.950	
9	5.64E-04	1.17E+03	1.17E+03	-0.569	
10	7.13E-04	1.08E+03	1.03E+03	5.082	
11	8.81E-04	9.12E+02	9.07E+02	0.465	
12	1.10E-03	7.89E+02	7.93E+02	-0.600	
13	1.41E-03	7.22E+02	6.81E+02	6.050	
14	1.80E-03	5.67E+02	5.93E+02	-4.403	
15	2.22E-03	5.17E+02	5.29E+02	-2.275	

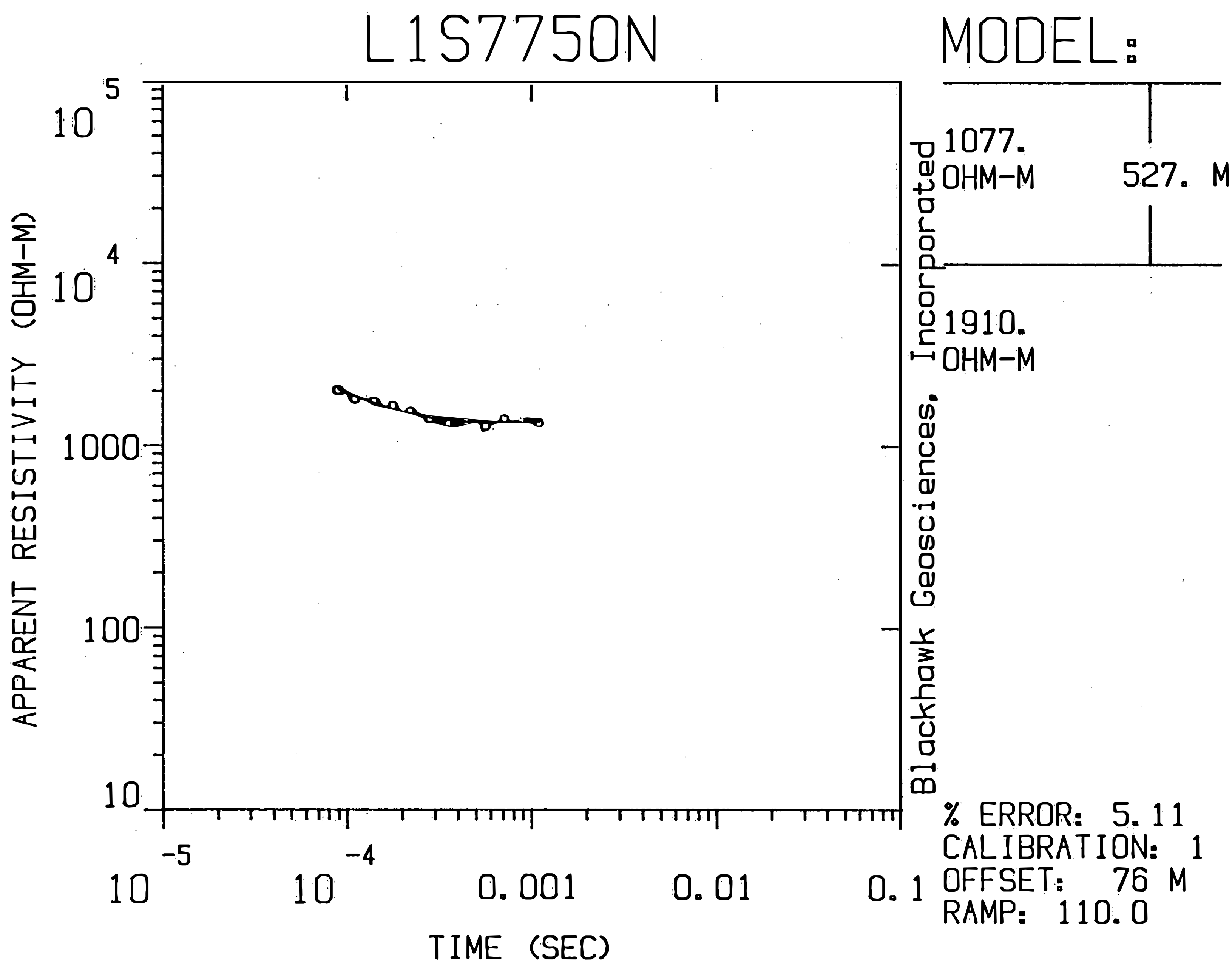
R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S7250N
1307 100N 7250NZ OPR H 6 8 +
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.33E-02, ANTILOG YIELDS 5.5058 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.34		
P 2	-0.01	0.01	
T 1	0.04	0.03	0.31
	P 1	P 2	T 1



L1S7750N
MODEL:
1077.
OHM-M
527. M
1910.
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 5.11
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S7750N

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		515.1	1690.0		
1076.57	526.6	-11.5	-37.6	0.5	0.5
1909.88					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.02E+03	2.06E+03	-1.795	
2	1.10E-04	1.81E+03	1.88E+03	-3.781	
3	1.40E-04	1.75E+03	1.72E+03	2.236	
4	1.77E-04	1.67E+03	1.59E+03	4.696	
5	2.20E-04	1.56E+03	1.50E+03	3.557	
6	2.80E-04	1.41E+03	1.43E+03	-1.642	
7	3.55E-04	1.34E+03	1.38E+03	-3.453	
8	4.43E-04	1.35E+03	1.36E+03	-0.112	
9	5.64E-04	1.28E+03	1.34E+03	-4.495	
10	7.13E-04	1.41E+03	1.34E+03	5.079	
11	8.81E-04	1.39E+03	1.35E+03	2.957	
12	1.10E-03	1.33E+03	1.37E+03	-2.619	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 12 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S7750N
1307 100N 7750NZ OPR H 6 8 +
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.17E-02, ANTILOG YIELDS 5.1136 %
LATE TIME PARAMETERS

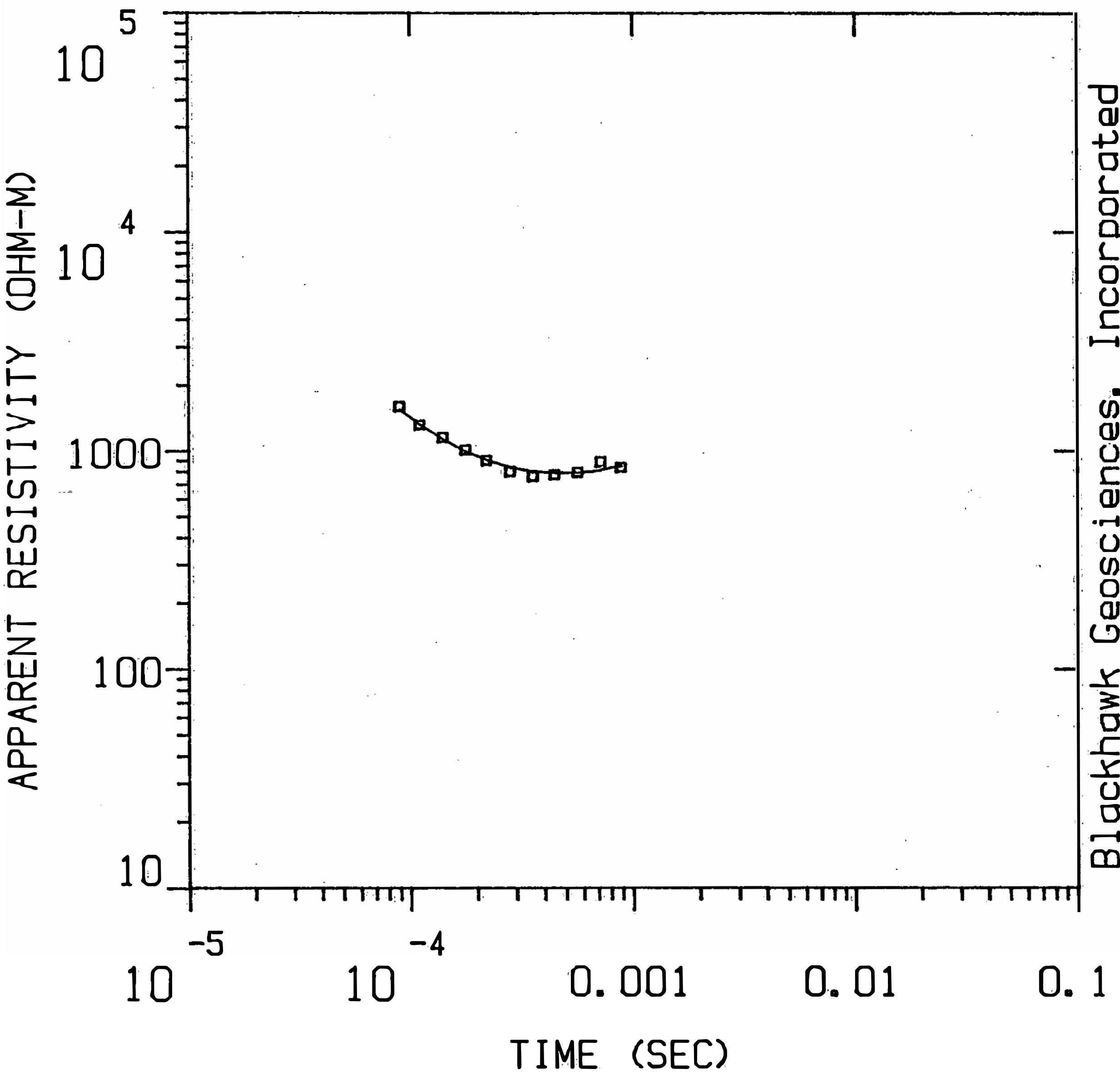
RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	T 1
P 1	1.00		
P 2	0.00	0.99	
T 1	0.00	-0.01	0.99

L1S8250N



MODEL:

954.
OHM-M 291. M

41.6
OHM-M 16.4 M

5471.
OHM-M

% ERROR: 5.58
CALIBRATION: 1
OFFSET: 76 M
RAMP: 110.0

L1S8250N

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		502.9	1650.0		
954.48	291.0	211.9	695.3	0.3	0.3
41.56	16.4	195.5	641.5	0.4	0.7
5471.45					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.60E+03	1.55E+03	3.343	
2	1.10E-04	1.32E+03	1.33E+03	-0.705	
3	1.40E-04	1.15E+03	1.13E+03	1.713	
4	1.77E-04	1.01E+03	9.96E+02	1.387	
5	2.20E-04	9.03E+02	9.06E+02	-0.354	
6	2.80E-04	8.02E+02	8.39E+02	-4.470	
7	3.55E-04	7.61E+02	8.02E+02	-5.082	
8	4.43E-04	7.78E+02	7.88E+02	-1.328	
9	5.64E-04	7.96E+02	7.93E+02	0.347	
10	7.13E-04	8.91E+02	8.17E+02	8.990	
11	8.81E-04	8.38E+02	8.54E+02	-1.965	

R: 76. X: 0. Y: 76. DL: 152. REQ: 84. CF: 1.0000
CLHZ ARRAY, 11 DATA POINTS, RAMP: 110.0 MICROSEC, DATA: L1S8250N
1307 100N 8250NZ OPR H 6 8 +
Ch.21 = 0.11 Ch.22 = 0.089 Ch.23 = 18 Ch.24 = 2
RMS LOG ERROR: 2.36E-02, ANTILOG YIELDS 5.5829 %
LATE TIME PARAMETERS

RUNON: 4 TURN OFF 4 TURN ON 30.00 Hz
TURN ON TIME CONSTANT: 110.00 MICROSEC

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.48				
P 2	0.21	0.38			
P 3	0.03	0.03	0.01		
T 1	0.29	-0.07	-0.04	0.74	
T 2	-0.20	-0.39	-0.04	0.11	0.39

Blackhawk Geosciences, Inc.

Massive Sulfide Target Detection

Massive sulfide type deposits can be high-grade ores of various base and precious metals, such as Red Dog, Alaska (copper-lead-zinc); Copper Canyon, Nevada (copper skarn with associated gold); and Stillwater, Montana (platinum group metals). Massive sulfides are characterized by connecting sulfide grains (e.g., pyrite, pyrrhotite, galena), so that low values of electrical resistivity result. They can, therefore, be mapped by various airborne and ground electromagnetic methods.

The search for these targets has moved to greater depth, because most shallow occurrences have likely been identified. Geophysical surveys assist exploration by locating the existence such massive sulfide zones at depth, and determination of their strike and dip. Drill hole programs are often planned on the basis of geophysical surveys. Airborne (INPUT) and ground based time domain EM (TDEM) have become the dominant geophysical tool for such targets. Blackhawk Geosciences, Inc. extensively surveys with three Geonics TDEM systems:

- Geonics EM-42 for exploration depths beyond 1,500 ft.
- Geonics EM-37 for exploration depths to about 1,500 ft.
- Geonics EM-47 for exploration depths to about 200 ft.

Two case histories are shown in this application note, one from the Stillwater Complex in Montana over terrain with substantial topographic relief, and one from the north-central States, where a thick cover of glacial till overlays host rocks.

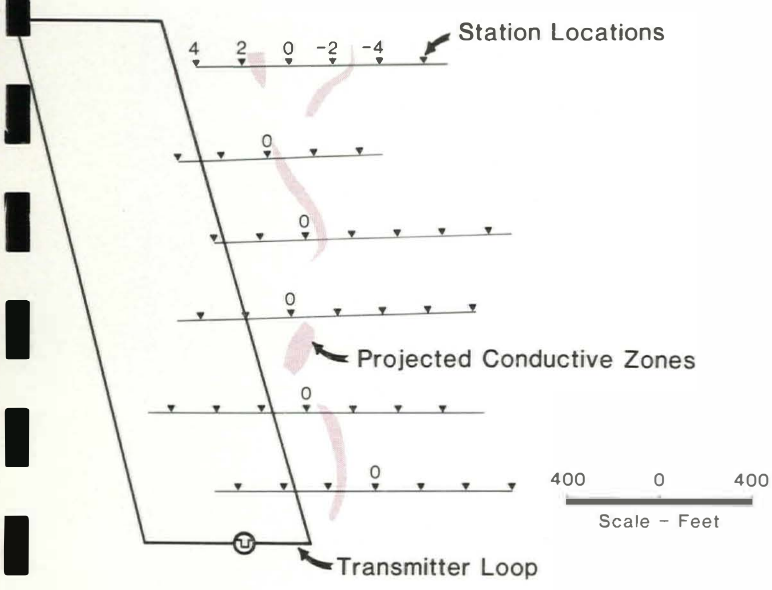


Figure 1: Survey Layout

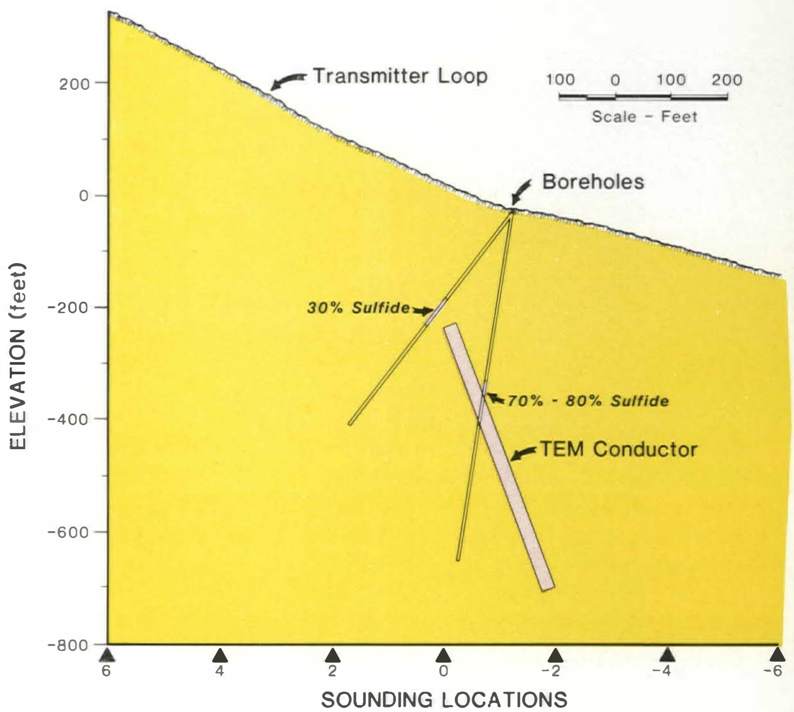


Figure 2: Cross Section

Stillwater, Montana

The Stillwater Complex is a mafic, igneous rock type in which sulfide rich zones have formed by separation. In this steep topographic terrain a large rectangular transmitter loop was laid parallel to the expected target strike, and profiles were run with a portable receiver on several lines from the same transmitter loop (Figure 1). It is common to measure three components of the magnetic field at each station.

Figure 1 shows layout of the transmitter loop, position of survey lines and surface projection of massive sul-fide zones derived from the TDEM survey. Computer models were used to match theoretical calculations with observed responses. The output of these models yield target depth, downward extent, strike, dip, and the product of target conductivity and thickness. Figure 2 shows the modeled target position and two superimposed drill holes. The high sulfide concentration observed in one drill hole (70 to 80 percent) is consistent with the model. A drill hole over the top of the target intercepted a halo of lower sulfide concentration.

This case history illustrates that TDEM surveys can be conveniently run in terrain with large topographic relief and minimum survey requirements. Stations need not be slope chained as is common in frequency domain EM (e.g., Max-Min).

North-Central States

Part of the north-central States is underlain by protozoic, volcanic-clastic terrain. The volcanic-associated massive sulfides that have formed are, as a group, predominantly stratiform accumulations of sulfide minerals, which formed on or near the sea floor by precipitation near the discharge site of hydrothermal fluids. A glacial cover of several hundred feet may overlay the basement rocks, and it is this glacial cover that necessitates the use of geophysics.

In this environment, and for these targets, it is again common to conduct TDEM ground surveys with large transmitter loops, and run several survey lines from such loops. Figure 3 shows surface and cross-section projections of a target defined from TDEM surveys. The target was confirmed by a subsequent drill hole.

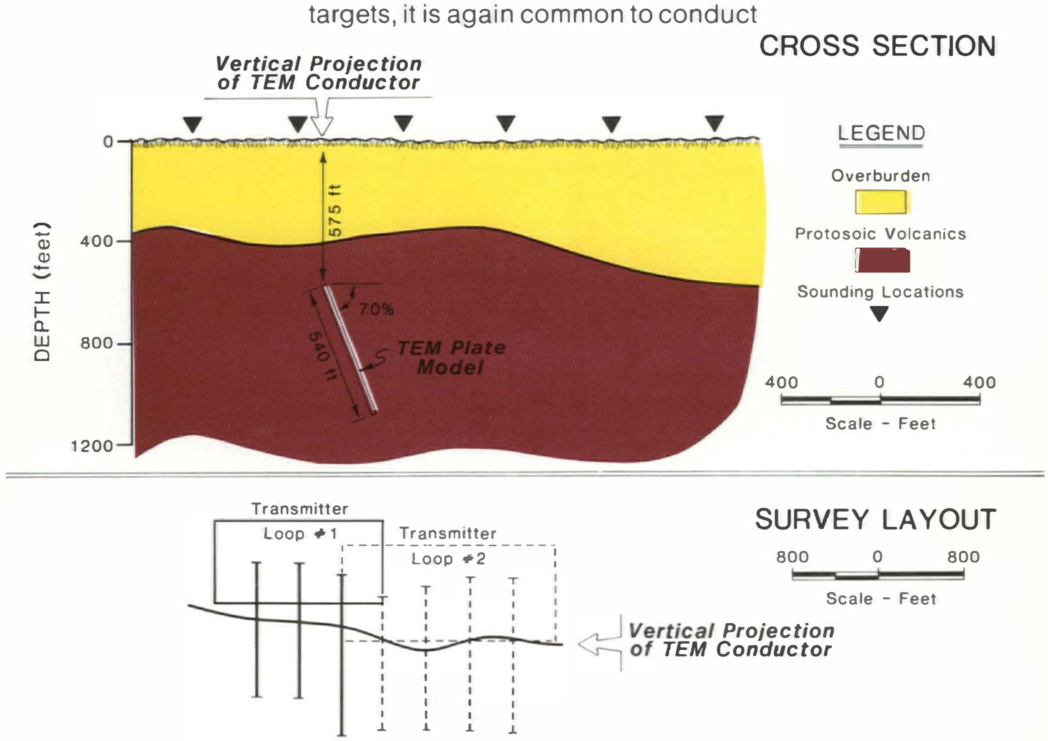


Figure 3: Cross Section and Survey Layout

Postscript

There are several ways to conduct TDEM surveys for detecting conductive zones, such as massive sulfides and fracture and shear zones. Figure 4 illustrates the various survey modes.

TDEM can now also be conveniently run in the HLEM mode with the EM-47. This unit is light weight and easily portable. It can replace frequency domain EM surveying (e.g., VLF, Max-Min, Genie) for exploration depths to about 200 ft.

The advantages of TDEM compared to frequency domain EM are:

- lower sensitivity to geologic noise, such as variation in overburden thickness and type
- smaller transmitter-receiver separation for equivalent exploration depth
- minimum land survey requirements and less sensitivity to topographic relief.

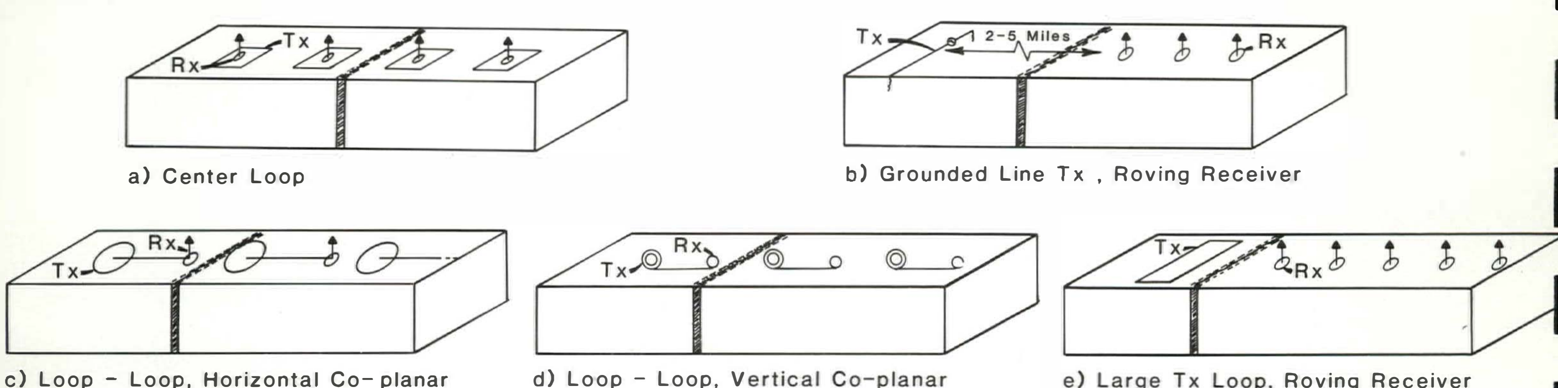


Figure 4: TDEM transmitter - receiver arrays

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